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The present volume contains the contributions from the Woods Hole Oceanographic Institution which appeared during 1940 in publications other than *Papers in Physical Oceanography and Meteorology;* also the Annual Report of the Director for 1939.

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Contribution No. 62

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TIME VARIABILITY OF HYDROGRAPHIC ELEMENTS DETERMINING THE DYNAMIC SITUATION IN THE WESTERN NORTH ATLANTIC [1]

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(Communicated by Henry B. Bigelow)

ABSTRACT

In 1936, 1937, and 1938 repeated temperature (and salinity) measurements over periods of 57 to 314 hours, at fixed depths (measured from the physical sea surface) in the western North Atlantic have revealed that, because of significant daily and day by day changes in the observed state of the sea, a measure of average conditions is not generally obtained from isolated individual samplings of the water column; a circumstance which reduces the significance of detail in patterns of geographic variation of oceanographic properties (as deduced from data of station networks). Remarks on this phenomenon in the Atlantic basins by various authors have recently been summarized by Seiwell [2] and are dispensed with here. In this paper it is proposed, first, to present a resumé of the results of repeated temperature measurements at three "Atlantis" Stations (2886, 2887, 3091) in the western basin of the North Atlantic, and, second, to apply the results of one of these (2887) to illustrate the effect of short period variations on dynamic computations of the state of the western Sargasso Sea and of the Gulf Stream system off the American coast.

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[1] Supported by a grant from the American Philosophical Society. Contribution No. 62 from the Woods Hole Oceanographic Institution.

[2] The Effect of Short Period Variations of Temperature and Salinity on Calculations in Dynamic Oceanography. Papers in *Physical Oceanography and Meteorology*, Vol. VII, No. 3, 1939.

Short Period Temperature Variations at Fixed Depths and Related Vertical Displacements in the Western Sargasso Sea

Station Data

Results of repeated temperature measurements to be discussed were obtained from "Atlantis" stations located in the western Atlantic basin between Bermuda and the Gulf Stream system, where, for considerable distance, in all directions, horizontal gradients of oceanographic properties are small. The temperature observations comprising a single sampling of the water column were made almost simultaneously at 18 levels between surface and 1200–1400 meters by using 18 pairs of reversing thermometers on a single wire; the time between successive samplings (comprising 18 items each) was about 60 minutes. At the stations discussed "Atlantis" was not anchored, but during operation, frequent observations of ship's drift (and favorable weather) enabled samplings to be made generally within a radius of 2 to 3 miles (in no case exceeding 5 miles) from the mean station positions tabulated in Table 1. Mean geographic positions of Stations 2887 and 3091 are nearly identical, both being located about 110 miles northwest of Bermuda; Station 2886 (about 100 miles to the south) is approximately 60 miles west of Bermuda.

TABLE 1

Station	λ	φ	Depth	Duration of Sampling 60° Time	Number of Samplings
2886	65° 59′ W	32° 19′ N	4830	23^h 46^m, June 16–08^h 28^m, June 19, 1937	50
2887	65° 56′ W	34° 01′ N	5216	23^h 16^m, June 19–13^h 34^m, June 22, 1937	41
				07^h 57^m, June 24–08^h 24^m, June 28, 1937	72
3091	65° 54′ W	34° 02′ N	5133	12^h 21^m, June 16–14^h 22^m, June 29, 1938	194

To reduce observations for analysis, individual temperature depth curves for each sampling were plotted and scaled both for temperatures at standard depths and for depths of standard isotherms; the scaled items being consolidated into averages, or used individually, as required. The density distributions at each station were determined by combining average temperatures at

standard depths and average depths of standard isotherms with salinity values scaled from the individual temperature salinity relationships.[3]

Daily and Total Temperature Ranges at Standard Depths
("Atlantis" Stations 2886, 2887, 3091)

Total temperature ranges [4] at standard depths (Table 2) were between 0.08° and 0.76° during $56^h\ 42^m$ of observation at Station 2886, between 0.50° and 2.71° during $158^h\ 45^m$ at Station 2887,

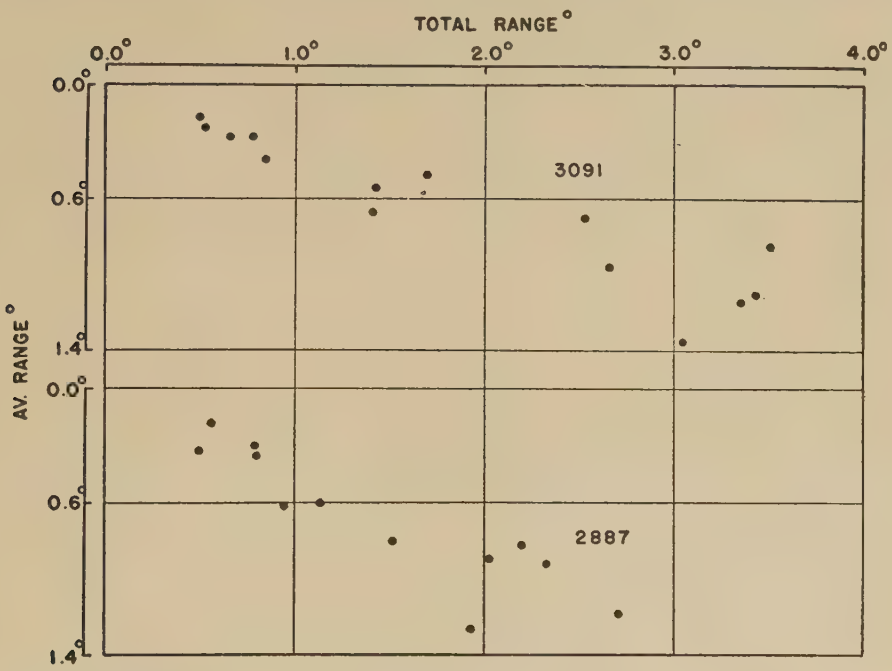

FIG. 1. Relationship. Total temperature range to average daily temperature range at standard depths for Stations 2887 and 3091, scales in degrees centigrade.

and between 0.50° and 3.52° during $314^h\ 01^m$ at Station 3091. The average daily (24 hour) temperature ranges [5] for these same stations were between 0.08° and 0.65° at 2886, between 0.18° and 1.26° at 2887, and between 0.17° and 1.35° at 3091 (Table 2). Vertical variations in magnitude of both the above ranges are closely related; depths characterized by the larger total variations

[3] Salinity values were determined for approximately 15 per cent of the samplings, and, thence, combined with corresponding temperatures to form temperature salinity relationships for each station (see Seiwell, 1939, footnote 2).

[4] Maximum temperature minus minimum temperature for the period specified.

[5] Average of all daily ranges extending from midnight to midnight.

are similarly characterized by the larger average daily ranges and vice versa (Fig. 1). Individual daily temperature ranges entering into computation of the average daily temperature ranges are subject to wide variability; for instance, daily ranges at depths of the minimum average daily range varied between 0.04° and 0.55° at Station 2887, and between 0.06° and 0.26° at Station 3091; likewise, at the depth of the maximum average daily range individual

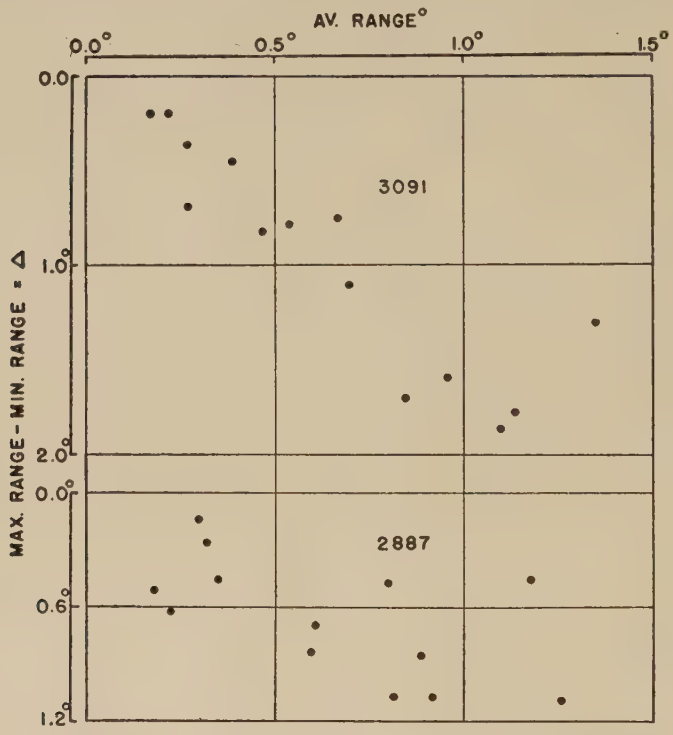

Fig. 2. Relationship. Average daily temperature range to difference between maximum and minimum individual daily temperature ranges (maximum range − minimum range = Δ) at standard depths for Stations 2887 and 3091.

daily temperature ranges were between 0.63° and 1.71° and between 0.90° and 2.20°, respectively. Greater differences in individual daily ranges (maximum daily range − minimum daily range) occur at depths characterized by the higher average daily temperature ranges, the general linear relationship between these statistics being illustrated by Fig. 2.

Other details of temperature variations at standard depths are given by Table 2, and examination shows that for any particular depth significant day by day variations occur in magnitude of the

TABLE 2

Depth	Average Temperature	Average Daily Temperature Range	Minimum Daily Temperature Range	Maximum Daily Temperature Range	Total Temperature Range
	Station 2886				
0	25.22°	—	—	—	—
50	—	—	—	—	—
100	18.71°	0.64°	0.59°	0.69°	0.74°
200	18.17°	0.08°	0.07°	0.08°	0.08°
300	17.99°	0.18°	0.17°	0.19°	0.19°
400	17.46°	0.13°	0.13°	0.13°	0.13°
500	16.83°	0.31°	0.30°	0.31°	0.39°
600	15.48°	0.47°	0.47°	0.47°	0.58°
700	13.51°	0.63°	0.62°	0.64°	0.76°
800	11.35°	0.65°	0.60°	0.69°	0.71°
900	9.03°	0.65°	0.60°	0.69°	0.69°
1000	7.19°	0.46°	0.27°	0.65°	0.65°
1100	5.87°	0.40°	0.38°	0.41°	0.41°
1200	5.19°	0.25°	0.21°	0.28°	0.28°
1300	—	—	—	—	—
	Station 2887				
0	24.55°	—	—	—	—
50	—	—	—	—	—
100	19.92°	0.89°	0.57°	1.42°	2.03°
200	18.27°	0.30°	0.18°	0.32°	0.79°
300	18.02°	0.32°	0.16°	0.42°	0.50°
400	17.53°	0.35°	0.10°	0.55°	0.80°
500	17.46°	0.18°	0.04°	0.55°	0.56°
600	17.13°	0.61°	0.24°	0.93°	0.95°
700	15.74°	1.26°	0.63°	1.71°	1.93°
800	13.56°	0.92°	0.36°	1.53°	2.33°
900	11.96°	0.82°	0.45°	1.51°	2.20°
1000	9.90°	1.18°	0.94°	1.39°	2.71°
1100	7.61°	0.80°	0.64°	1.11°	1.52°
1200	6.13°	0.60°	0.27°	1.10°	1.13°
1300	—	—	—	—	—
	Station 3091				
0	24.34°	—	—	—	—
50	20.08°	1.35°	0.90°	2.20°	3.05°
100	18.44°	0.54°	0.22°	1.01°	1.43°
200	17.91°	0.27°	0.08°	0.77°	0.78°
300	17.67°	0.17°	0.06°	0.26°	0.50°
400	17.38°	0.27°	0.15°	0.51°	0.66°
500	16.78°	0.67°	0.34°	1.09°	1.41°
600	15.51°	0.96°	0.36°	1.95°	2.66°
700	13.73°	1.10°	0.47°	2.33°	3.44°
800	11.65°	1.14°	0.73°	2.50°	3.36°
900	9.44°	0.85°	0.38°	2.08°	3.52°
1000	7.56°	0.70°	0.35°	1.45°	2.53°
1100	6.28°	0.47°	0.24°	1.06°	1.70°
1200	5.50°	0.39°	0.22°	0.67°	0.85°
1300	4.99°	0.22°	0.11°	0.31°	0.53°

temperature variations, and, that all minimum or maximum temperature variations (average daily ranges, variations in individual daily ranges, total ranges, etc.) occur at similar parts of the water column. The first characteristic, indicating that the magnitude

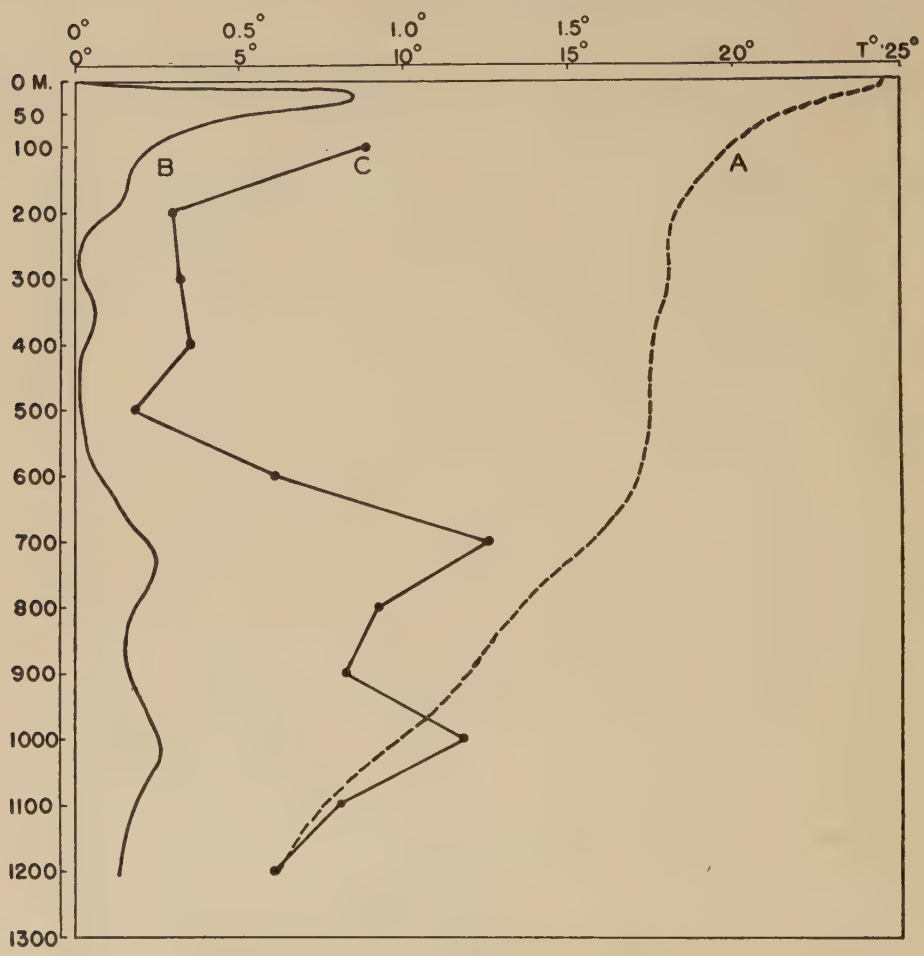

FIG. 3. Temperature variations during 6 days at Station 2887. A = average vertical temperature distribution; B = average vertical variation of temperature, $\frac{\Delta T^\circ}{\Delta z} \times 10^2$ degrees per meter (referred to uppermost scale); C = average daily temperature ranges at standard depths referred to uppermost scale.

of the disturbance of the water column varies from day to day, is discussed with reference to vertical displacements, whereas the second is further examined with reference to the vertical temperature stratification of the water column.

Daily temperature ranges are larger for depths where thermal stratification is greatest, a circumstance brought out for Stations 2886, 2887, and 3091 by Figs. 3 and 4. Conditions at all three stations are essentially similar, and, as illustrated for the two latter,

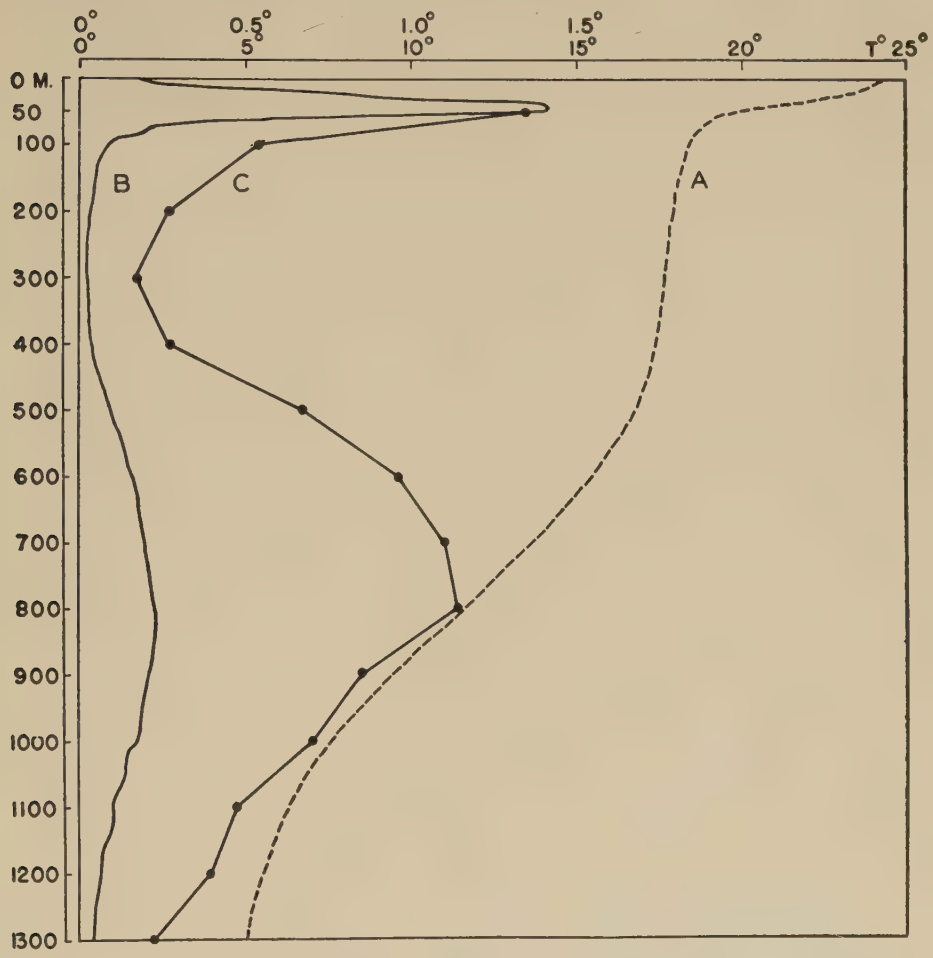

FIG. 4. Temperature variations during 13 days at Station 3091. A = average vertical temperature distribution; B = average vertical variation of temperature, $\frac{\Delta T^\circ}{\Delta z} \times 10^2$ degrees per meter referred to uppermost scale; C = average daily temperature ranges at standard depths referred to uppermost scale.

changes in magnitude of average daily temperature ranges are sensitive to small variations in thermal stratification. Thus, at Stations 2887 and 3091, between the 17° and 18° isotherms, where temperature (and density) changes slowly with depth, $\frac{\Delta T^\circ}{\Delta z} = 0.08^\circ$

$\times 10^{-2}$ to 0.9×10^{-2} per meter, average daily temperature ranges were only 0.17° to 0.35°; in the overlying surface layer (in the vicinity of 20°–21°) where $\frac{\Delta T^\circ}{\Delta z}$ attains values up to $14.2^\circ \times 10^{-2}$, average daily temperature ranges were up to 1.35°, while, in the intermediately stratified deeper water (between 17° and 6°), values of $\frac{\Delta T^\circ}{\Delta z} = 2.3 \times 10^{-2}$ to 2.5×10^{-2}, average daily temperature ranges up to 1.14°–1.26° were observed.

Likewise, total temperature ranges (for the different observation periods) and variations in individual daily temperature ranges will bear the same relationship to thermal stratification as the average daily temperature ranges. Thus, during the 13 days of observation at Station 3091, the smallest total variation of 0.50° occurred in the least stratified water at 300 meters depth and the largest of 3.52° occurred in the deeper more stratified water at 900 meters depth. Other corresponding relationships are brought out by comparison of Figs. 1, 2, 3, and 4; the minimum temperature disturbances occur where the water column is least stratified thermally, and, maximum where it is most strongly stratified.

Daily and Total Vertical Displacements of the Water Column ("Atlantis" Stations 2886, 2887, 3091)

To specify vertical displacements at particular depths in the water column, reference is made to various isotherms (average depths tabulated in Table 3), the apparent changes in positions of which (in the western Sargasso Sea) may be considered as resulting from vertical movements of the water particles, a circumstance deduced because of the small horizontal isothermal gradients.[6]

Total vertical displacement ranges of water particles as shown by standard isotherms were between 39 and 165 meters during $158^h\ 45^m$ at Station 2887 and between 38 and 227 meters during $314^h\ 01^m$ at Station 3091. These large vertical displacements result from short period vertical oscillations having periods of 24 lunar hours or less superimposed on longer period trends; characterizations of the latter, by fitting straight lines to the 12 daily

[6] For example, in this region the maximum gradient of 10° isotherm is 1.33 meters per kilometer, and of the 17° isotherm 1.00 meter per kilometer (see papers in *Physical Oceanography and Meteorology*, Vol. V, No. 2, page 17).

TABLE 3

Isotherm	Station 2886		Station 2887					Station 3091				
	Average Depth	Average Daily Range	Average Depth	Average Daily Range	Minimum Daily Range	Maximum Daily Range	Total Range	Average Depth	Average Daily Range	Minimum Daily Range	Maximum Daily Range	Total Range
20.00°	—	—	98	26	21	23	39	56	19	5	28	38
19.00°	84	40	150	25	12	35	41	79	25	11	55	82
18.00°	288	54	300	74	57	94	124	179	69	29	107	196
17.75°	—	—	—	—	—	—	—	260	81	40	106	227
17.50°	393	49	449	97	36	161	165	367	73	34	116	170
17.25°	—	—	—	—	—	—	—	438	83	39	142	159
17.00°	482	36	618	81	43	117	131	476	79	42	149	172
16.00°	567	30	687	70	51	97	129	566	67	27	144	172
15.00°	625	24	733	57	39	80	115	631	59	26	120	156
14.00°	676	29	776	54	27	74	117	686	53	24	103	144
13.00°	725	38	829	57	27	85	112	737	53	30	108	145
12.00°	772	32	899	49	41	67	98	784	53	30	110	155
11.00°	814	25	954	52	47	61	117	829	48	30	110	172
10.00°	856	29	995	47	39	59	106	873	43	21	111	170
9.00°	901	31	1035	47	34	62	98	921	40	18	106	162
8.00°	953	21	1079	44	28	63	96	974	42	18	103	157
7.00°	1012	30	1135	42	33	58	81	1039	47	21	101	172
6.00°	1085	46	1211	45	34	69	74	1131	53	24	110	168
5.00°	1241	48	—	—	—	—	—	1293	53	27	85	122

TABLE 4

Isotherm	$y=a+bx$		Average Depth June 17	Average Depth June 28
	a	b		
20.00°	59.26	−0.59	56.2	50.1
19.00°	88.05	−1.37	83.3	67.9
18.00°	235.30	−8.39	200.6	139.0
17.75°	324.16	−9.77	282.1	212.2
17.50°	360.97	0.85	345.2	386.0
17.25°	402.40	5.28	394.0	469.3
17.00°	433.61	6.26	427.4	506.1
16.00°	530.41	5.38	525.3	592.5
15.00°	598.58	4.82	596.5	657.9
14.00°	653.81	4.86	653.6	714.5
13.00°	705.00	4.77	706.8	765.4
12.00°	752.80	4.60	755.2	809.4
11.00°	799.71	4.28	802.5	851.3
10.00°	845.67	4.08	849.3	895.1
9.00°	894.26	3.89	898.7	941.6
8.00°	949.11	3.59	954.2	994.5
7.00°	1013.63	3.67	1016.7	1058.6
6.00°	1109.57	3.07	1110.1	1152.9
5.00°	1269.71	3.65	1288.9 (June 18)	1328.4

average depths of each isotherm at Station 3091, and determining the coefficients a and b of the general equation:

$$y = a + bx$$

by the method of least squares, are given in Table 4. The coefficient, b, denoting the daily change in average depth of isotherms shows a pronounced relationship to vertical variation of density. In the surface layer, between 20.0° and 17.75°, the downward slope

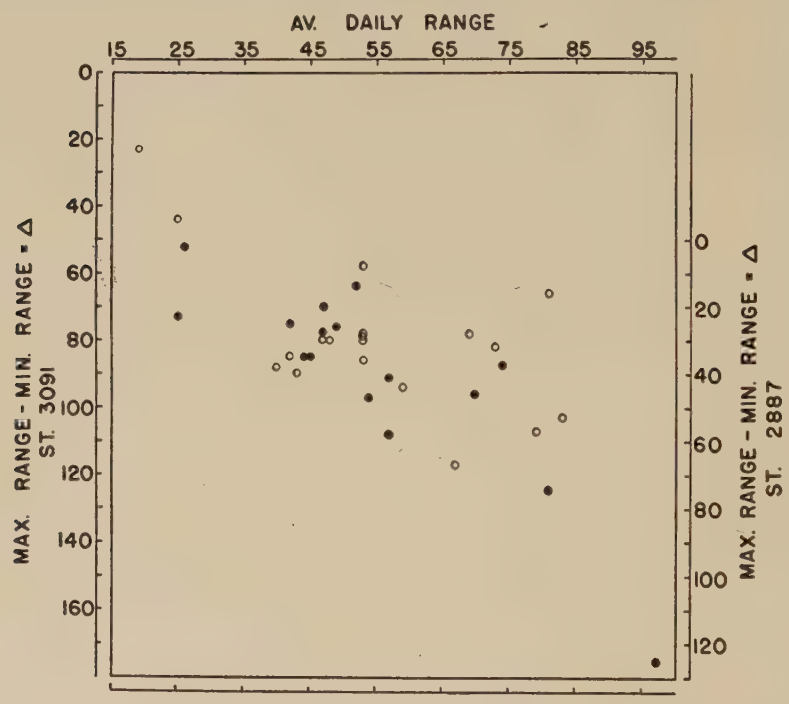

FIG. 5. Relationship. Average daily vertical displacement range of isotherms to difference between their maximum and minimum individual daily vertical ranges (maximum range − minimum range = Δ) for Stations 2887 (closed circles) and 3091 (open circles), scales in meters.

of isotherms increased from 0.59 to 9.77 meters per day; in the least stratified part of the water column, between 17.75° and 17.50°, there occurred an abrupt reversal of slope, and slightly deeper, the trend of the 17.0° isotherm sloping upward at an average rate of 6.26 meters per day. In still deeper water, with increasing stability, isothermal slopes continue upward, but at a slower rate, at 6° the linear rate being reduced to 3.07 meters per day. Thus, because of the abrupt phase reversal between 17° and 18° iso-

therms, the average vertical distance between them increased from 227 meters on June 17 to 367 meters on June 28; above 17.5° the water became increasingly warmer and below (to 1200 meters) increasingly colder.

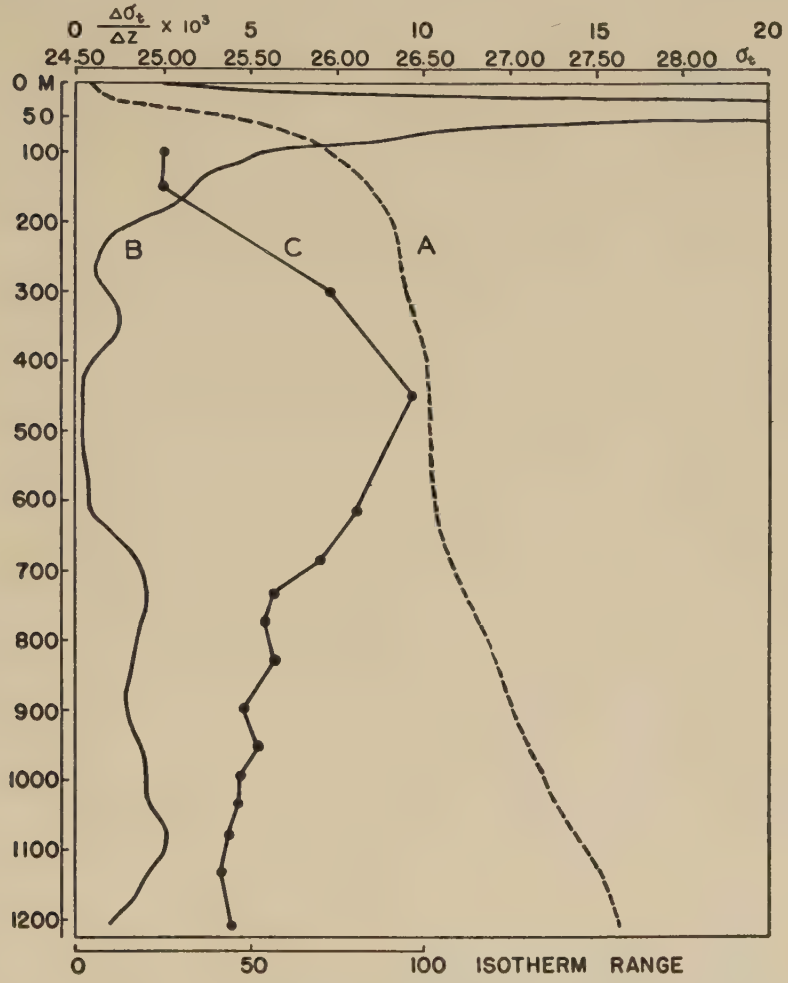

FIG. 6. Density (σ_t) distribution and vertical displacement of isotherms during 6 days at Station 2887. A = average vertical distribution of density, σ_t; B = average vertical variation of density, $\frac{\Delta\sigma_t}{\Delta z} \times 10^3$, units of σ_t per meter (uppermost scale); C = average daily vertical displacement ranges of isotherms (20°–6°, in meters, lower scale).

Average daily vertical displacement ranges [7] of the above isotherms (Table 3) were between 24 and 54 meters at Station 2886,

[7] Average of all daily vertical displacement ranges from midnight to midnight.

between 25 and 97 at Station 2887 and between 19 and 83 meters at Station 3091. Vertical variations in magnitudes both of daily average and total ranges are related, isotherms characterized by

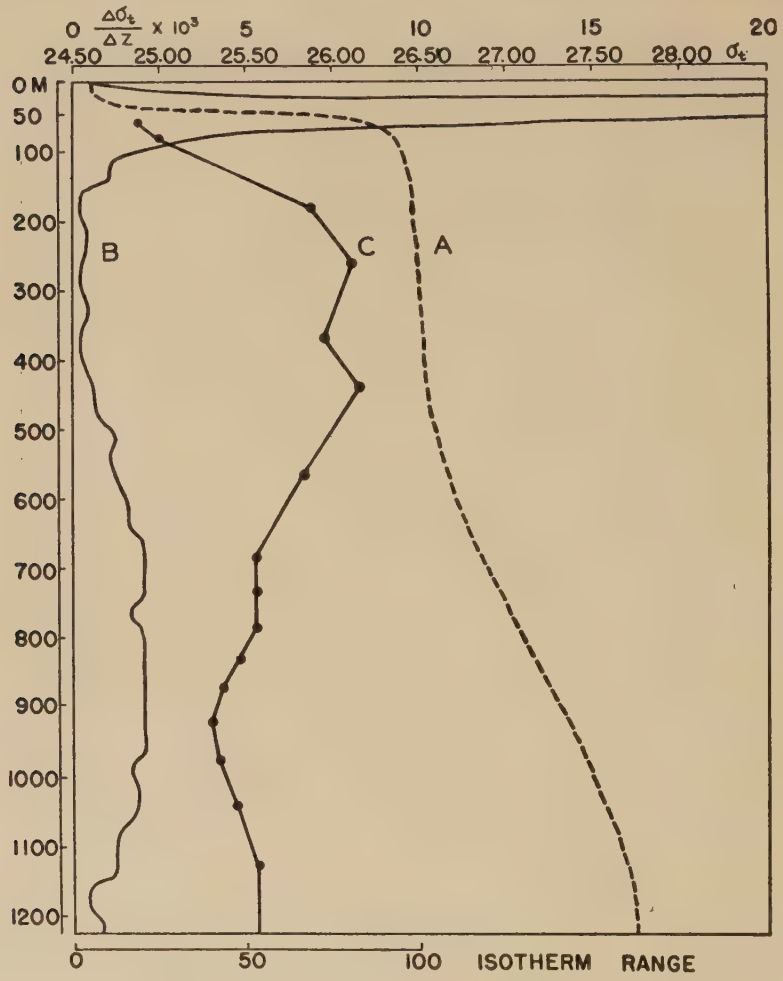

FIG. 7. Density (σ_t) distribution and vertical displacements of isotherms during 13 days at Station 3091. A = average vertical distribution of density, σ_t; B = average vertical variation of density, $\frac{\Delta\sigma_t}{\Delta z} \times 10^3$, units of σ_t per meter (uppermost scale); C = average daily vertical displacement ranges of isotherms (20°–5°, in meters, lower scale).

the larger total variations being, in general, characterized by the larger average daily vertical ranges and vice versa. Certain exceptions to this generalization occur within the least stratified water, between the 17° and 18° isotherms, where there is a phase

reversal in long period trends as previously brought out. Daily vertical displacement ranges entering into the computation of the average daily vertical displacement ranges of individual isotherms are, like temperature ranges, subject to wide variability. Thus, the individual daily ranges of the isotherms having the minimum average daily vertical range varied between 12 and 35 meters at Station 2887 (19° isotherm) and between 5 and 28 meters (20° isotherm) at Station 3091, and, for the isotherms showing maximum daily average ranges, individual daily ranges were between 36 and 161 meters (17.5° isotherm) at 2887 and between 39 and 142 meters (17.25° isotherm) at Station 3091; isotherms characterized by the larger average daily ranges showed, in general, greater variability in their individual daily ranges. The latter being illustrated by Fig. 5 where are plotted (for Stations 2887 and 3091) differences between minimum and maximum daily ranges (Δ) against average daily displacement ranges; the relationship is similar to that for temperature variations at standard depths.

Although ranges of vertical displacements of isotherms vary from day to day (Table 3) a definite relationship to the vertical density distribution $\left(\frac{\Delta\sigma_t}{\Delta z}\right)$ persists. Thus, at Stations 2887 (Fig. 6) and 3091 (Fig. 7) magnitudes of vertical displacements, at a maximum where the water is least stable (to depths of 1200–1300 meters, $\frac{\Delta\sigma_t}{\Delta z}$ = approximately 2×10^{-4}), are suppressed with increasing stratification. In this least stratified water, between 17° and 18° isotherms,[8] average daily vertical displacements at Station 2887 were 81 to 97 meters and at Station 3091, 73 to 83 meters; in the intermediately stratified deep water $\left(\frac{\Delta\sigma_t}{\Delta z} = 2.6 \times 10^{-3}\right)$, average daily ranges of isotherms (15°–6°) decreased to 42–57 meters

[8] At both stations the least stratified water was bounded by the 17° and 18° isotherms, and although observations were made at identical dates on successive years (Table 1) their average depths differed respectively by 121 and 142 meters, thus:

		Depth	$\frac{\Delta\sigma_t}{\Delta z} \times 10^3$	σ_t
Station 2887	18°	300	0.2–1.2	26.41
	17°	618		26.57
Station 3091	18°	179	0.2–0.6	26.46
	17°	476		26.56

at Station 2887 and to 40–59 meters at Station 3091; and, in the strongly stratified surface layer $\left(\frac{\Delta\sigma_t}{\Delta z} = 74 \times 10^{-3}\right)$, average daily ranges of isotherms (20° and 19°) were reduced to 19–26 meters (Table 3).

Relationship of Daily Temperature and Vertical Displacement Ranges to Temperature Stratification of the Water Column and their Apparent Day by Day Changes

The inverted relationship between magnitudes of daily temperature and daily displacement ranges to vertical temperature stratification [9] of the water column (illustrated by average daily values for Stations 2887 and 3091, Fig. 8) brings out that damping of vertical displacements by increased vertical stratification is insufficient to offset an increasing time variation of temperature at the fixed depths concerned. Thus, for instance, at Stations 2887 and 3091 as the vertical temperature gradient $\left(\frac{\Delta T^\circ}{\Delta z} \times 10^2 \text{ per m}\right)$ increased tenfold, from 0.2° to 2.0°, the average daily temperature range at the depths concerned increased approximately fivefold to correspond to a damping of average vertical displacements of the water particles by approximately one-half.

As a result of the preceding discussions of day by day changes in daily temperature ranges at standard depths, and of the magnitudes of daily displacements of isotherms, it is inferred that the internal wave mechanism causes day by day changes in the observed state of the sea; and a qualitative comparison based on average daily vertical displacements of whole degree isotherms, between 19° and 6°, for Stations 2887 and 3091 (Fig. 9) shows that, relatively speaking, both quiet and disturbed days may be expected. Thus, for instance, at Station 3091, during the 12 day period of observation, maximum disturbances of the water column on June 22 were nearly three times the minimum disturbances five days later, on June 27; abrupt changes in displacements of the water column may also occur from one day to the next; as, for instance (at Station 3091), on June 21, the average displacements of whole degree isotherms (between 19° and 6°) during the 24 hours

[9] Comparisons of Figs. 3, 4, 6, and 7 show that the vertical distribution of density (σ_t) is chiefly controlled by the vertical temperature distribution; consequently, since temperature stratification and density stratification are nearly identical the terms may, for purposes of this discussion, be used synonymously.

of 50 meters, increased to 93 meters on June 22, and then dropped off to 41 meters on June 23. Other day by day changes for stations concerned are brought out by Fig. 9. The close correspondence between magnitudes of average vertical displacements

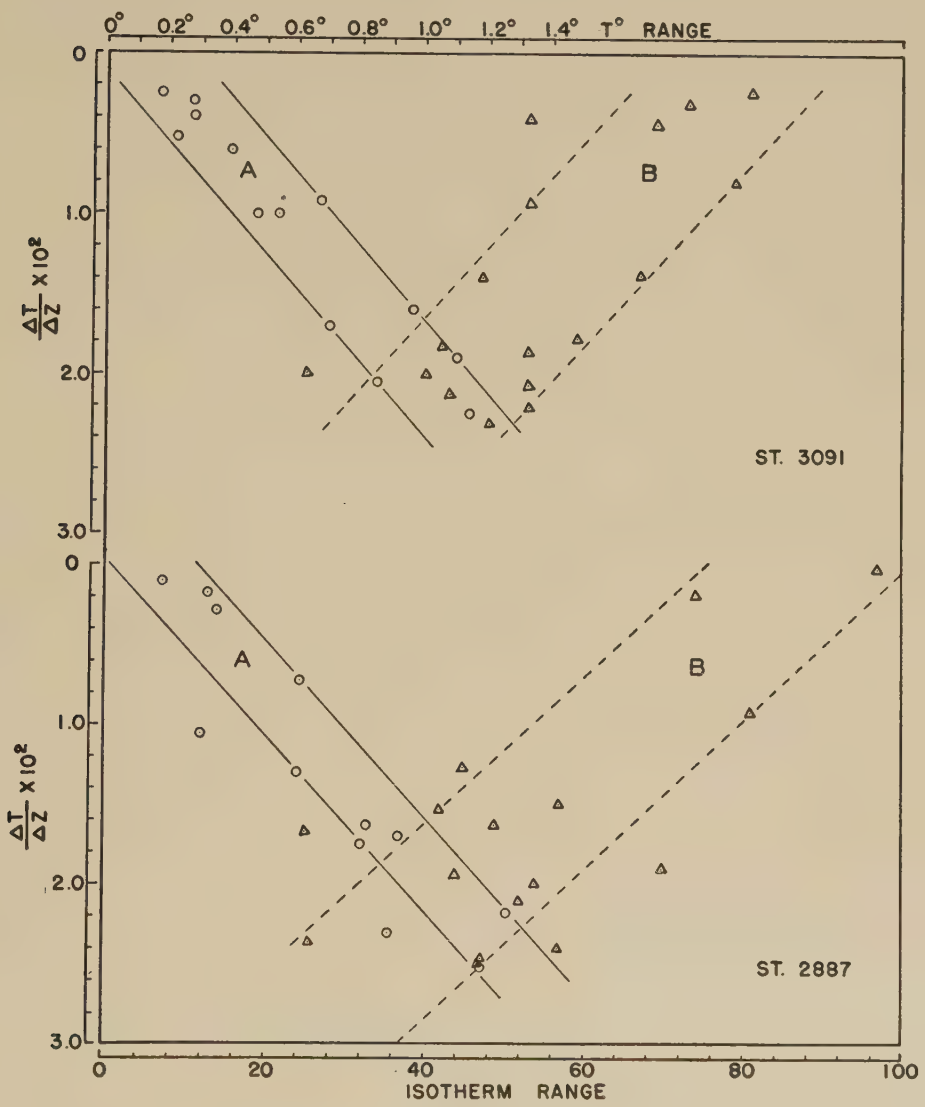

FIG. 8. Relationship. Average daily temperature ranges at standard depths, *A*, and average daily vertical displacement ranges of isotherms, *B*, to the average vertical variations of temperature $\frac{\Delta T^\circ}{\Delta z} \times 10^2$ (degrees per meter) for the water column of Stations 2887 and 3091.

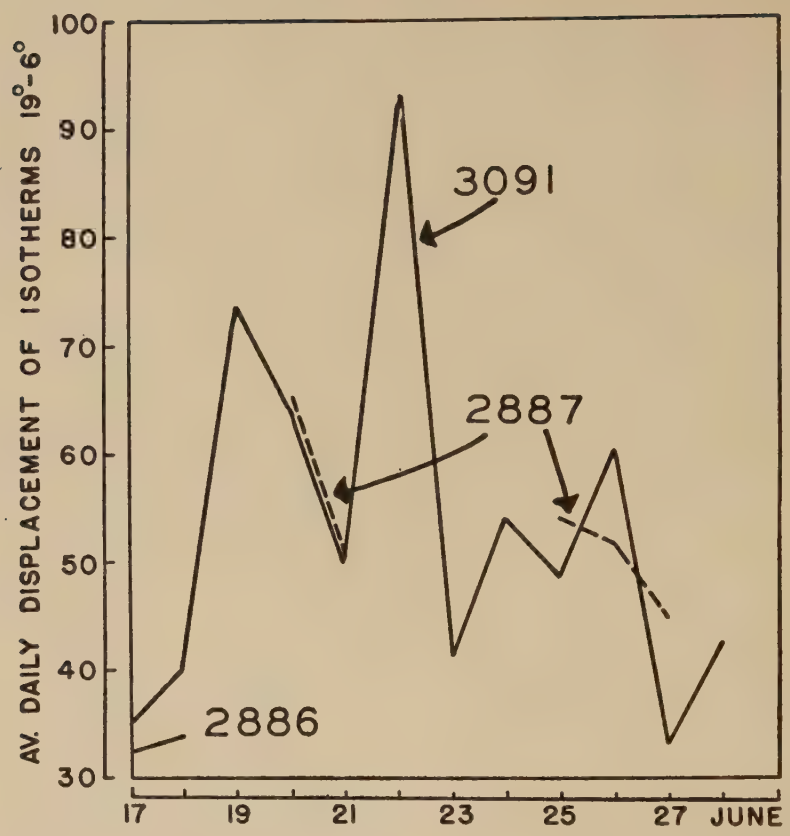

Fig. 9. Average daily vertical displacements of all unit isotherms between 19° and 6° for Stations 2886 (2 days), 2887 (5 days) in 1937 and for Station 3091 (12 days) in 1938.

of whole degree isotherms, between 19° and 6°, for Stations 2886, 2887, and 3091, for identical dates in 1937 and 1938 may be purely coincidental.

Time Alterations in Dynamic Computations for Individual Verticals in the Sea Resulting from Short Period Variations of Oceanographic Properties

Application to the Western Sargasso Sea (24 hour period at Station 2887)

For representing the equilibrium state of the sea, as deduced from temperature and salinity observations along a series of verticals, it is convenient to compute dynamic heights of isobaric surfaces above a reference level, lying usually between 1200 and 2000

decibars.[10] Hence, for illustrative purposes of time variations in computed dynamic heights of isobaric surfaces as may occur along a single vertical in the western Sargasso Sea during a 24 hour period, the serial temperature and salinity measurements taken between $07^h\ 57^m$, June 24, and $07^h\ 33^m$, June 25, at "Atlantis" Station 2887 are considered, results of computations being summarized in Tables 5 and 6. In the present case, the variations in dynamic heights of isobaric surfaces result from the uneven changes in dynamic thicknesses of isobaric sheets; details of this are given in Table 5, as anomalies of dynamic thickness of successive isobaric sheets (bounded by standard isobaric surfaces) for 9 samplings of the water column during the 24 hour period.[11] Columns headed Δ (Table 5) represent differences in dynamic thicknesses between successive samplings (or the computed amounts of shrinking and stretching that isobaric sheets have undergone during the time interval), and illustrate (on comparison with Table 6) that changes in thickness of individual isobaric sheets frequently are greater than the total integrated changes in dynamic height at the sea surface of the whole water column. Thus, between series C ($13^h\ 01^m$) and B ($10^h\ 25^m$), the change in dynamic height, above the 1200 decibar surface, was only 0.20 dynamic centimeters (Table 6), whereas thickness of isobaric sheets between 100–200 decibars and between 200–300 decibars increased 0.80 and 1.00 dynamic centimeters, respectively (Table 5), while at the same time that between 1100 and 1200 decibars decreased 0.80 dynamic centimeters. Likewise, between series F ($22^h\ 12^m$) and E ($18^h\ 28^m$), variations in dynamic thickness of isobaric sheets, while not so large, were completely balanced; the summation of the total changes over the water column equaled zero (Table 6). The time change between series H ($04^h\ 05^m$) and I ($07^h\ 33^m$) was the only case in which every single variation in dynamic thickness of the isobaric sheets was in the same (negative) direction; hence, summation gave the maximum effect at the surface. Large variations occurred in the highly stable water above 200 decibars, and smaller ones where the water column was least stable (between 400 and 500 decibars).

Successive upward summations of time variation in dynamic

[10] For details and tables, see: Bjerkness, *Dynamic Meteorology and Hydrography*, Publication No. 88, Carnegie Institution of Washington, 1910.

[11] Anomalies of dynamic height are obtained by successive summations of principal columns (A, B, etc.) in Table 5.

TABLE 5

Stratum D-Bars	A 6/24/37 $7^h\ 57^m$	B − A = Δ cms.	B 6/24/37 $10^h\ 25^m$	C − B = Δ cms.	C 6/24/37 $13^h\ 01^m$	D − C = Δ cms.	D 6/24/37 $16^h\ 02^m$	E − D = Δ cms.	E 6/24/37 $18^h\ 28^m$	F − E = Δ cms.	F 6/24/37 $22^h\ 12^m$	G − F = Δ cms.	G 6/25/37 $01^h\ 37^m$	H − G = Δ cms.	H 6/25/37 $04^h\ 05^m$	I − H = Δ cms.	I 6/25/37 $7^h\ 33^m$
0– 50	14.30	0.05	14.35	0.05	14.40	0.10	14.50	0.55	15.05	−0.40	14.65	−0.25	14.40	−0.10	14.30	−0.35	13.95
50– 100	11.60	−0.05	11.55	−0.05	11.50	0.20	11.70	0.70	12.40	−0.40	12.00	−0.10	11.90	−0.40	11.50	−0.70	10.80
100– 200	19.80	−0.60	19.20	0.80	20.00	−0.60	19.40	0.30	19.70	−0.20	19.50	0.40	19.90	−0.80	19.10	−0.60	18.50
200– 300	17.60	−0.40	17.20	1.00	18.20	−0.70	17.50	0.10	17.60	−0.20	17.40	−0.10	17.30	0.10	17.40	−0.30	17.10
300– 400	17.00	−0.20	16.80	0.20	17.00	0.10	17.10	0.00	17.10	−0.10	17.00	−0.20	16.80	0.20	17.00	−0.20	16.80
400– 500	16.80	0.00	16.80	−0.10	16.70	0.10	16.80	0.00	16.80	0.00	16.80	0.00	16.80	0.00	16.80	−0.10	16.70
500– 600	16.80	−0.10	16.70	0.10	16.80	0.20	17.00	−0.20	16.80	0.20	17.00	0.00	17.00	0.00	17.00	−0.10	16.90
600– 700	16.00	−0.10	15.90	0.10	16.00	0.40	16.40	−0.40	16.00	0.60	16.60	0.00	16.60	0.20	16.80	−0.30	16.50
700– 800	14.60	0.00	14.60	0.00	14.60	0.30	14.90	−0.30	14.60	0.60	15.20	0.10	15.30	0.10	15.40	−0.50	14.90
800– 900	13.60	0.00	13.60	−0.30	13.30	0.00	13.30	−0.10	13.20	0.50	13.70	−0.20	13.50	0.50	14.00	−0.50	13.50
900–1000	12.30	−0.20	12.10	−0.30	11.80	−0.30	11.50	0.20	11.70	0.20	11.90	−0.30	11.60	0.70	12.30	−0.20	12.10
1000–1100	10.00	0.10	10.10	−0.50	9.60	−0.40	9.20	0.50	9.70	−0.30	9.40	0.10	9.50	0.40	9.90	−0.10	9.80
1100–1200	7.70	0.60	8.30	−0.80	7.50	−0.20	7.30	0.40	7.70	−0.50	7.20	0.40	7.60	0.10	7.70	0.00	7.70

Time variations in anomalies of dynamic thickness of standard isobaric sheets during a 24 hour period, $7^h\ 57^m$, June 24–$7^h\ 33^m$, June 25, 1937, at Station 2887.

thicknesses (Δ values in Table 5) of isobaric sheets give amounts of variation in dynamic heights of standard isobaric surfaces as computed for successive samplings of the water column (Table 6), and illustrate the magnitude of the discrepancies that may be induced in projections of dynamic topographies of these surfaces in a region such as the one represented by Station 2887. Time variations in computed dynamic heights are irregular throughout the water column and those at the sea surface are not proportional to those at deeper lying isobaric surfaces. Thus, for example, between the series taken at $10^h\ 25^m$ and $13^h\ 01^m$ (Table 7), dynamic

TABLE 6

Pressure D-Bars	$10^h\ 25^m$–$7^h\ 57^m$	$13^h\ 01^m$–$10^h\ 25^m$	$16^h\ 02^m$–$13^h\ 01^m$	$18^h\ 28^m$–$16^h\ 02^m$	$22^h\ 12^m$–$18^h\ 28^m$	$01^h\ 37^m$–$22^h\ 12^m$	$04^h\ 05^m$–$01^h\ 37^m$	$07^h\ 33^m$–$04^h\ 05^m$
0	−0.90	0.20	−0.80	1.75	0.00	−0.15	1.00	−3.90
50	−0.95	0.15	−0.90	1.20	0.40	0.10	1.10	−3.60
100	−0.90	0.20	−1.10	0.50	0.80	0.20	1.50	−2.90
200	−0.30	−0.60	−0.50	0.20	1.00	−0.20	2.30	−2.30
300	0.10	−1.60	0.20	0.10	1.20	−0.10	2.20	−2.00
400	0.30	−1.80	0.10	0.10	1.30	0.10	2.00	−1.80
500	0.30	−1.70	0.00	0.10	1.30	0.10	2.00	−1.70
600	0.40	−1.80	−0.20	0.30	1.10	0.10	2.00	−1.60
700	0.50	−1.90	−0.60	0.70	0.50	0.10	1.80	−1.30
800	0.50	−1.90	−0.90	1.00	−0.10	0.00	1.70	−0.80
900	0.50	−1.60	−0.90	1.10	−0.60	0.20	1.20	−0.30
1000	0.70	−1.30	−0.60	0.90	−0.80	0.50	0.50	−0.10
1100	0.60	−0.80	−0.20	0.40	−0.50	0.40	0.10	0.00
1200	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Time change in dynamic heights (dynamic centimeters) of standard isobaric surfaces between successive observation series during a 24 hour period at Station 2887 (calculated from a reference surface of 1200 decibars).

height of the sea surface increased 0.20 dynamic centimeters, but at the 700 and 800 decibar surfaces it decreased 1.90 dynamic centimeters; whereas, between $04^h\ 05^m$ and $7^h\ 33^m$, change in dynamic height of the sea surface was at a maximum (representing a continuous accumulation of changes in the deeper water).

Application to the Gulf Stream
(24 hour period at Station 2855)

Dissimilarities between dynamic situations of the western Sargasso Sea and the Gulf Stream system (along the American coast) as illustrated by vertical distributions of density (Fig. 10) are such that not only will vertical oscillations cause greater variations of oceanographic characteristics in the latter, but horizontal displace-

ments of the water masses may also be effective in bringing about temperature variations at standard depths. Thus, for illustrative purposes, time variations based on four series of observations

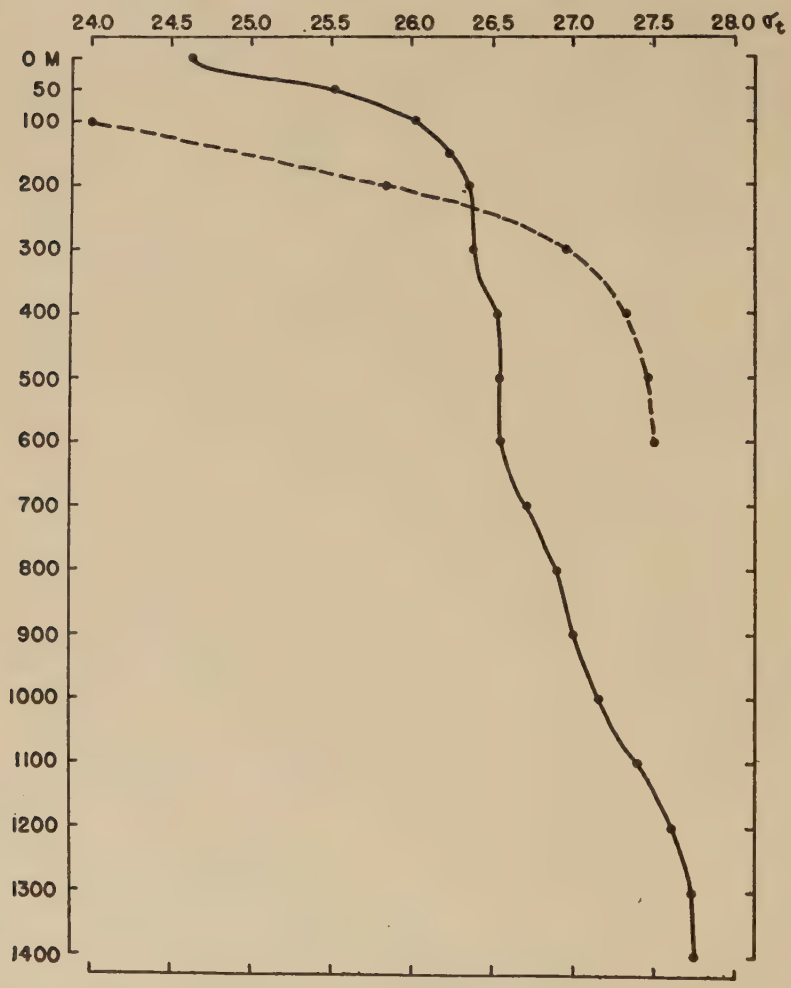

FIG. 10. Vertical distribution of density (σ_t) at Station 2887 (full line) in the Western Sargasso Sea, and at Station 2855 (dashed line) in the Gulf Stream off the Florida coast.

(A: 21^h 31^m, April 18; B: 03^h 23^m, April 19; C: 11^h 23^m, April 19; D: 15^h 21^m, April 19, 1937) at "Atlantis" anchor Station 2855 in the Straits of Florida [12] (25° 37′ N, 79° 51′ W, depth 680 meters)

[12] These 4 samplings were selected, as being sufficient for illustrative purposes, from a series of 12 at Station 2855, which is one of a group of 5 anchor Stations (2854–2858) across the Florida Straits. Methods of computation are identical with those used for

are summarized in Table 7. The variations in dynamic heights during this 24 hour period (last column, Table 7), at 100 and 200 decibars, were 4.3 and 2.3 times the maxima recorded for identical surfaces in the Sargasso Sea region, while time variations in isobaric sheet thicknesses were, on the average, 3.7 to 1.2 times those in the latter region. Perhaps noteworthy is the fact that positive and negative short period changes in dynamic thickness over the water column were not as irregular as at 2887, a result possibly of the internal wave mechanism acting on a shallower water column or perhaps of a difference in character of the mechanism itself.

TABLE 7

Pressure Decibars	A 4/18/37 $21^h\ 31^m$	B − A = Δ	B 4/19/37 $03^h\ 23^m$	C − B = Δ	C 4/19/37 $11^h\ 23^m$	D − C = Δ	D 4/19/37 $15^h\ 21^m$	Cms. Range
100	67.55	12.95	80.50	−6.60	73.90	−2.25	71.65	12.95
150	51.25	10.45	61.70	−7.40	54.30	−0.05	54.25	10.45
200	39.10	7.45	46.55	−7.20	39.35	1.95	41.30	7.45
250	30.55	4.65	35.20	−4.80	30.40	1.60	32.00	4.80
300	24.20	2.30	26.50	−2.75	23.75	1.35	25.10	2.75
350	19.05	0.90	19.95	−1.45	18.50	1.05	19.55	1.45
400	14.60	0.40	15.00	−0.75	14.25	0.80	15.05	0.80
450	10.60	0.35	10.95	−0.50	10.45	0.65	11.10	0.65
500	6.90	0.30	7.20	−0.35	6.85	0.45	7.30	0.45
550	3.40	0.15	3.55	−0.15	3.40	0.20	3.60	0.20
600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Time variations in anomaly of dynamic height (from the 600 decibar surface) in the Gulf Stream at Station 2885 during the period, $21^h\ 31^m$, April 18 to $15^h\ 21^m$, April 19, 1937.

Effect of Short Period Variations of Oceanographic Properties on Computations of Dynamic Topography, Current Velocities, and Volume Transports

Application to the Western Sargasso Sea

Because of regional differences in horizontal distributions of oceanographic properties, the significance of their short period variations to dynamic computations is relative; comparative situations are brought out by brief discussions of two hydrographically

Station 2887, except that (because of shallower depth) dynamic heights of isobaric surfaces are referred to the 600 decibar surface, and because of unstable conditions close to the surface the water column is considered only below 100 meters depth. Hence, comparisons of water columns for the two regions from identical reference levels would, no doubt, show somewhat modified results (see papers in *Physical Oceanography and Meteorology*, Vol. VII, No. 3, 1939).

dissimilar parts of the North Atlantic; *e.g.*, the western Sargasso Sea and the Gulf Stream system off the American coast.

Computation of dynamic slopes of isobaric surfaces in the western Sargasso Sea (from the 2000 decibar reference level) as based on "Atlantis" Stations 2875 (35° 21′ N, 66° 46′ W), 2877 (34° 09′ N, 66° 02′ W) and 2879 (32° 50′ N, 65° 03′ W) shows a decrease of 7.95 dynamic centimeters in dynamic height of the sea surface between 2875 and 2877 and of 2.88 dynamic centimeters between 2877 and 2879 (Fig. 11). Hence, a short period variation of 3.9 dynamic centimeters (as was computed to occur within a few hours at Station 2887; Table 6) would be sufficient to bring about resulting discrepancies between 49 and 139 per cent in dynamic slopes of the sea surface in this region. Variations within the water column are of the same order of magnitude; between Stations 2875 and 2877 the decrease in thickness of isobaric sheets was between 0.8 to 2.8 times, and between 2877 and 2879 it was 0.09 to 3.0 times the computed average time change in thickness of isobaric sheets at Station 2887.

Since computations of current velocities are based on dynamic slopes of isobaric surfaces, similar proportionate discrepancies are to be expected when applied to this region. Thus the current velocity, C, is given by

$$C = \frac{1}{2\omega \sin \varphi} \cdot \frac{H_A - H_B}{L},$$

where $H_A - H_B$ represents differences in dynamic heights of isobaric surfaces above an arbitrary deep reference surface, between two verticals (A and B), separated by a distance, L, φ the mean latitude of A and B, and ω the angular velocity of the earth's rotation.

The data of the present discussion also permit information to be brought out concerning the magnitude of possible discrepancies in computations of volume transports both in the western Sargasso Sea and the Gulf Stream system. Thus, it can be shown that the volume transport (V), above a surface of zero geopotential, between two verticals (A and B) in the sea is closely given by the formula

$$V = \frac{10}{2\omega \sin \varphi} (\Delta Q_A - \Delta Q_B) m^3 \sec^{-1},$$

where

$$\Delta Q = \int_z^0 \Delta H dz,$$

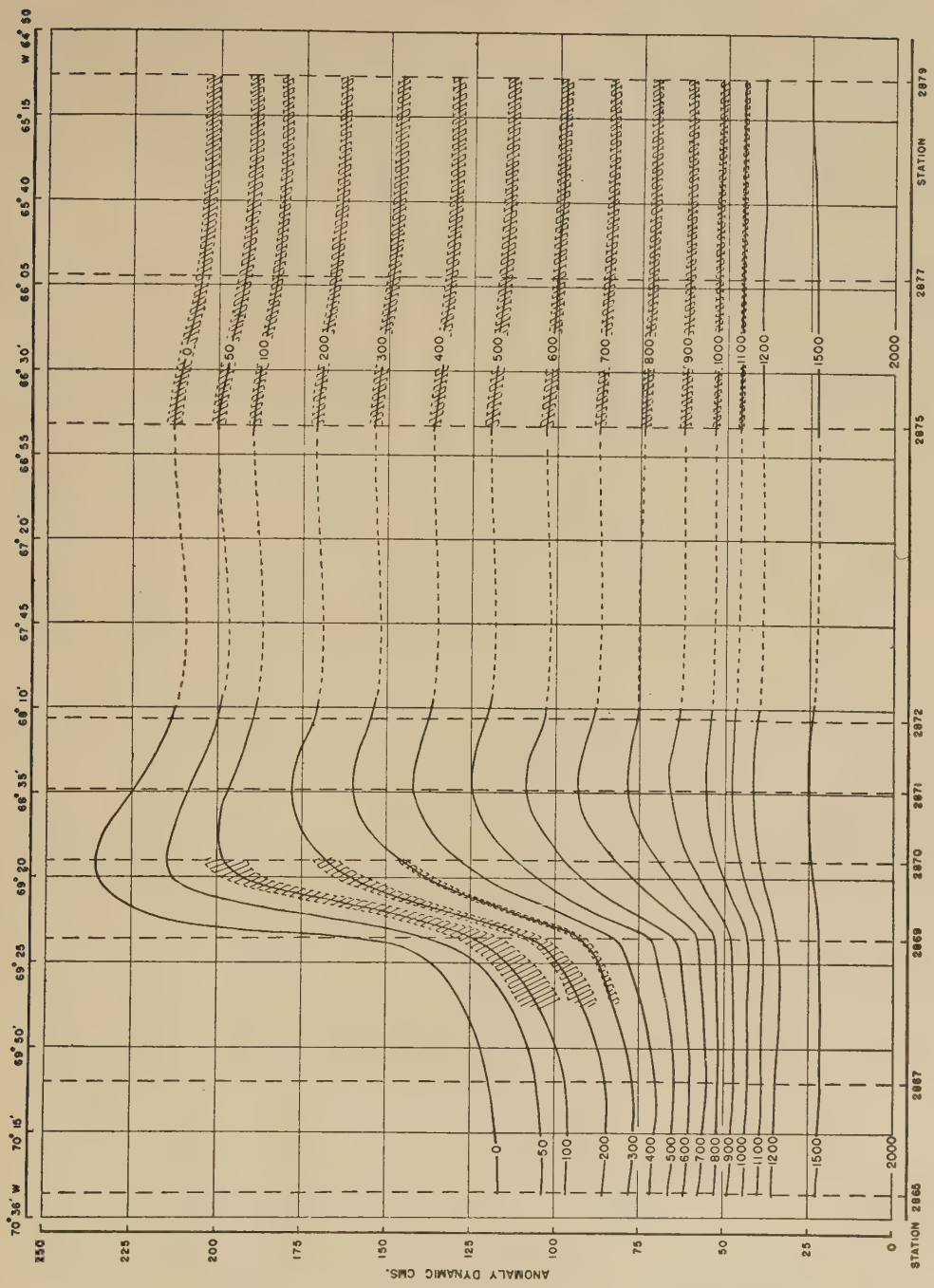

FIG. 11. Dynamic slopes of standard isobaric surfaces from 2000 decibar surface across the Gulf Stream as determined by "Atlantis" Stations 2865 (39° 24′ N, 70° 33′ W) to 2872 (36° 43′ N, 68° 13′ W) and over the Western Sargasso Sea as determined by Stations 2875 (35° 21′ N, 66° 46′ W) to 2879 (32° 50′ N, 65° 03′ W). Shaded areas represent range of short period fluctuations in dynamic height observed in the Gulf Stream at Station 2855 and in the Western Sargasso Sea at Station 2887.

ΔH being the anomaly of dynamic height. $\Delta Q_A - \Delta Q_B$ is designated as $\Delta' Q$.

In the western Sargasso Sea, the computed time variation of ΔQ (referred to 1200 decibars, equation 11) during a 24 hour period (beginning $07^h\ 57^m$, June 24) at Station 2887 had an average value

$$(\Delta Q)_M = 948.521 \text{ m}^3 \text{ sec}^{-2},$$

the average absolute change between series of observations was

$$(\Delta' Q) = 8.533 \text{ m}^3 \text{ sec}^{-2}$$

and the average absolute hourly change (over the 24 hour period) was

$$(\Delta' Q) = 2.905 \text{ m}^3 \text{ sec}^{-2},$$

and the maximum ΔQ difference $(\Delta' Q)$ between any two series was

$$(\Delta' Q)_{\max} = 30.000 \text{ m}^3 \text{ sec}^{-2}.$$

The consequence of these results to transport computations is relative (as for current computations), depending on $\Delta' Q$ variations in the area. The effect is variable and while the largest recorded variations of Q or ΔQ are not the usual rule, they occur with sufficient frequency so that even occasional large errors in transport computations from uncontrolled data [13] may vitiate, or at least seriously interfere with, conclusions of regional and seasonal differences in transport.

As an illustration of the horizontal changes in ΔQ $(\Delta' Q)$ to be expected in the Western Sargasso Sea, based on four groups of "Atlantis" Stations in this region, viz.: 2875 (35° 21′ N, 66° 46′ W; June 7, 1937), 2877 (34° 09′ N, 66° 02′ W; June 8, 1937), 2879 (32° 50′ N, 65° 03′ W; June 8, 1937), 1220 (32° 40′ N, 65° 00′ W; April 17, 1932), 1221 (32° 51′ N, 66° 25′ W; April 18, 1937), 1360 (32° 43′ N, 65° 00′ W; August 28, 1932), and 1361 (33° 13′ N, 66° 20′ W; August 28, 1932), the computed range was from 19.120 to 107.687 $\text{m}^3 \text{ sec}^{-2}$, the average $\Delta' Q$ value being 53.614 $\text{m}^3 \text{ sec}^{-2}$. Comparison of these horizontal ΔQ variations with time ΔQ variations during a 24 hour period at Station 2887 shows that the maximum ΔQ difference between any two sets of observations at Station 2887 (30.00 $\text{m}^3 \text{ sec}^{-2}$) was nearly 56 per cent of the average $\Delta' Q$ value in the Western Sargasso Sea, and between 28 and 157 per cent of individual horizontal ΔQ differences $(\Delta' Q)$. The aver-

[13] Data obtained without knowledge of time variation of temperature and salinity.

age change of ΔQ between observation series at Station 2887 (8.533 m^3 sec^{-2}) was 16 per cent of the average horizontal $\Delta' Q$ value and from 8 to 45 per cent of the individual values.

For this group of stations the values of V/L, or total volume transports (computed from equation 9) divided by the linear distances between stations, ranged from 13.80 m^3 sec^{-1} per m to 101.60 m^3 sec^{-1} per m, and the average was

$$\frac{V}{L} = -47.98 \text{ m}^3 \text{ sec}^{-1} \text{ per m},$$

which may be the best value of transport per linear meter between latitudes 35° 21′ N–32° 40′ N and longitude 65° 00′ W–66° 46′ W. Variations in ΔQ, V, and V/L result from local, annual, seasonal, and short period variations of oceanographic elements, the partial effects of long period and local components being overshadowed by the superimposed short period variations.

Application to the Gulf Stream System off the American Coast

Short period time variations of dynamic heights at Station 2855 (previously discussed) when transposed to the dynamic pattern of this current system (based on a profile of six "Atlantis" Stations, transverse to the current, extending south 33° east from Montauk Point: 2865, 39° 23.5′ N, 70° 33′ W; 2867, 38° 41′ N, 70° 00′ W; 2869, 38° 02′ N, 69° 18′ W; 2870, 37° 34′ N, 68° 55′ W; 2871, 37° 08′ N, 68° 34′ W; 2872, 36° 43′ N, 68° 13′ W; June 4–6, 1937) may be shown to be of less relative significance than in the Western Sargasso Sea. Anomalies of dynamic height, computed from 2000 decibar surface, are illustrated by Fig. 11; shaded areas over the 100, 200, and 300 decibar surfaces represent 24 hour ranges in elevation deduced from continuous measurements at Station 2855. The main part of the Gulf Stream is well marked by the strong dynamic slope between Stations 2867 and 2870 (131 kilometers), the difference in dynamic height of the sea surface being 115.83 dynamic centimeters, and that at the 100 decibar surface being 100.30 dynamic centimeters. Thus, the average slope of the 100 decibar surface, over a horizontal distance of 131 kilometers, of 0.76 dynamic centimeters per kilometer, would (based on information from Station 2855) be subject to short period variation of about 13 per cent, whereas this same surface in the Western Sargasso Sea, with an average slope from 0.044 to 0.016 dynamic centimeters per kilometer (over horizontal distances of 149 to 172

kilometers), may be subjected to variations ranging from 50 to more than 100 per cent.

Computed current velocities for the Gulf Stream are subject to proportionate variations. However, it seems likely that such variations will affect velocity computations for the Gulf Stream most where horizontal velocities are least, so that largest errors may be expected in computations applying near the boundaries of the Gulf Stream and to its weaker counter currents.

Horizontal variation of ΔQ ($\Delta' Q$) per unit distance in the Gulf Stream section off Montauk Point ($\Delta' Q = 640.160$ m^3 sec^{-2} over 213.9 kilometers) was more than eight times that in the Western Sargasso Sea (average $\Delta' Q = 53.614$ m^3 sec^{-2} over 148 kilometers); and its maximum value ($\Delta' Q = 444.010$ m^3 sec^{-2} over 62 kilometers) was nearly nine times the maximum recorded for the latter region ($\Delta' Q = 107.687$ m^3 sec^{-2} over 134.4 kilometers), and after correcting for differences in latitude, the average volume transport per meter of the Gulf Stream ($V/L = 370.54$) was 7.7 times the average for the Western Sargasso Sea ($V/L = 47.98$), and its maximum ($V/L = 801.37$), approximately eight times the maximum ($V/L = 101.60$) for the latter region. The total volume transport of the Gulf Stream between Stations 2867 and 2871 is calculated, on the basis of the data under discussion, to be 71.62 m^3 sec^{-1}, and, it is likely that discrepancies in volume transport computations for the Gulf Stream system, will, like current computations, be less than in the Western Sargasso Sea or dynamically similar regions; within the former, larger percentage departures are to be expected in computations involving transports of the counter currents. In this respect the maximum time variation of ΔQ at Station 2887 (30.000 m^3 sec^{-2}) represents between 7 and 31 per cent of the ΔQ change across the Gulf Stream proper, but approximately two and one-half times the ΔQ change involving the western boundary between Stations 2865 and 2867.

Contribution No. 72

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Some New Flagellates from the Woods Hole Area

James B. Lackey

Students of marine Protozoa find such a wealth of material that it is difficult to study the phylum as a whole. A study of small flagellates obtained by centrifuging sea water or by concentrating plankton or by subjecting tubes to rapid pressure changes may also give one the urge and did not belong to the dinoflagellates or choanoflagellates probably the best known marine flagellate group. A number of the smaller free water forms commonly occur in the sea and there is also a large exclusively marine group. Dobell (1925) described 71 species of marine Phytomastigoda not inclusive of Dinoflagellata or Choanomastigoda. In the summer of 1937 34 species of flagellates were listed by Lackey (1939) from the Woods Hole area, exclusive of these same two groups.

Twenty four samples were taken between June 1 and September 15, 1937, when previous population was carefully checked. The usual procedure was to centrifuge from 150 to 1000 ml. Hence the supernatant water and keep the sediment in the refrigerator and the examination was finished since a rise in temperature to usual laboratory conditions is sufficient to mature spores. Numbers of organisms were counted and any unfamiliar one which occurred with some frequency were either studied at once or the slides were put into moist chambers and if the organisms persisted they were later studied at leisure. This procedure was valuable because some organisms reproduced in the interim, or became quiescent, or revealed details concerning food or life history which were of much importance in identification. After examination, samples which were not preserved were inoculated into various media and growing cultures of a few of these unfamiliar forms were secured.

The organisms described below occurred with sufficient frequency to be classed as valid species, moreover as they have not been found in previous of available literature.

Acrobrachyon [illegible] gen. et sp. nov.

Fig. 1, 2

Cellular membrane, under regulated membrane plasma, thinly, stiff, [illegible] flagellum attached, leaving the slide, [illegible] nonmotile and bear flagella usually long, [illegible] one nucleus chromatophore 1 [illegible] paranucleus [illegible] posterior plasmate [illegible] [illegible] [illegible] long max. 11 μ, lorica long max. 10 μ.

This small organism was rather common in samples in June. The small cell, oblong in form, never filled the lorica, which tapers to a point. The lorica is rounded in front, somewhat laterally compressed, tapering posteriorly. Midway on each side a wing emerges, resulting in a flat, wedge shaped pro-

Contribution No. 72 of the
Woods Hole Oceanographic Institution

terior portion of the lorica. It is colorless, thin, smooth. A single tenuous flagellum, about four times cell length emerges near a small anterior vesicle, apparently a contractile vacuole. Mouth absent. Two bright yellow brown chromatophores, ribbon like and somewhat irregular, are longitudinally disposed near the periphery of the cell. No stigma; nucleus not discernable in living forms; there are a few minute spheres in the otherwise homogeneous cytoplasm. Nutrition probably holophytic. Swims with a slow rotation. Reproduction not observed. The structure, motility and yellow brown chromatophores place this organism in the Chrysophyceae; the single apical flagellum places it in the suborder Cromulinineae. But its peculiar lorica does not fit into any of the present families, and it might be necessary to erect a family in which there is a distinct lorica but a simple vacuole system. Because the creature is so like a Chromulina with a shell, the writer does not feel justified in the creation of a new family. Provisionally placed in the class Chrysophyceae.

Stylochromonas minuta gen. et sp. nov.

Fig. 3

Cellulae minutae, late ovales, basi stipitatae, collo anteriore, glabro, hyalino vel haud distincto minutae; flagello singulo, longo, tenuissimo; chromatophoris 2, aureo-fuscis, arcuatis, marginem versus dispositis; stigmate nullo; nucleo centrali; sphaeris minutis paucis plasmate immersis; cell. long. 5-8 μ, colli long. 6 μ, stipitis long. 5-10 μ.

This minute form was fairly common in July on debris in the harbor. Its stiff stalk is short, usually about body length; the cell is broadly oval, 5-8 microns long, and is topped by a single, smooth, slightly flaring protoplasmic collar, about 6 microns long. A single flagellum is about twice body length and very vibratile at its distal end, but rather rigid proximally. Two golden brown curved chromatophores are peripherally located. There is a small median nucleus and a few oil drops posteriorly. No stigma. No evidence of holozoic nutrition, or reproduction was seen.

Chrysophyceae with membranous collars have not previously been described, and the close relationships of this flagellate are uncertain. *Pedinella hexacostata Wysotzki* is stalked, but has no collar; its stalk is contractile, not stiff; and there are six chromatophores. Stylochromonas probably belongs in the class Chrysophyceae, and in a new order, **Stylochromonadales** whose members are sessile, naked, and with a membranous collar; for the present, the above form must represent the only genus and species of this order.

Ochromonas marina sp. nov.

Fig. 4

Cellulae variabiles, cylindraceae, apice truncatae, basi rotundatae, verruculosae; flagellis 2, inaequalibus, levi fundo exerentibus; vesicula contractili, singula, subapicali; chromatophoris 2, arcuatis, aureo-fuscis; plasmate antice homogeneo, postice granuloso; cell. long. max. 35 μ, lat. 18 μ.

A fairly large Ochromonas of variable size, but commonly about 30 microns long. Cell cylindrical, truncate anteriorly, rounded posteriorly, this half having a characteristic warty appearance. Two slightly subequal flagella emerge from a slight mouth depression; the longer is about body length. Near their base is a contractile vacuole, emptying at long intervals. The two chromatophores are golden brown peripheral bands, smooth in contour. No nucleus visible in the living animal. Small black amorphous granules and refringent spheres in the cytoplasm. This species like others of its genus, ingests other Protista and at such times exhibits decided amoeboid changes. Reproduction not observed. Swims rapidly in a spiral. Common in Vineyard Sound in July. This large and beautiful Ochromonas is probably nearest *O. variabilis* Meyer, but differs in having a longer secondary flagellum and in the constant warty protuberances of the posterior end.

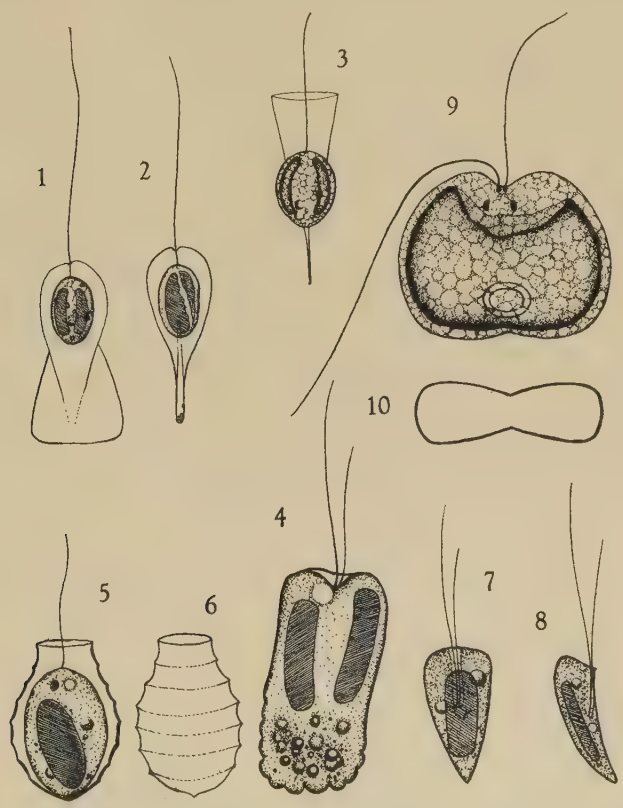


Fig. 1. *Angulochrysis erratica*, above; Fig. 2. Same, side; Fig. 3. *Stylochromonas minuta;* Fig. 4. *Ochromonas marina;* Fig. 5. *Chrysococcus cinctus*, optical section; Fig. 6. Same, shell; Fig. 7. *Cryptochrysis atlantica*, above; Fig. 8. Same, side; Fig. 9. *Heteromastix fissa*, entire; Fig. 10. Same, x-section.

Chrysococcus cinctus sp. nov.

Figs. 5, 6

Cellulae minimae, ovatae, lorica ovata, apice late aperta, 7-8 praecincta, sulcata, fusca, involucratae, basi adnatae; flagello singulo, tenui; cytoplasmate granuloso, stigmate praedito; chromatophoro fusco; long. 5 μ.

A very small form, common at all times. Animal ovoid in shape, attached posteriorly to a shell the same shape, except for a large opening in front. It is comprised of 7-8 concave rings as shown in Fig. 5, and is brown in color so as to obscure details of the organism within. A brown chromatophore, stigma and a few granules are visible, however. The animal swims slowly in a straight path. Reproduction was not seen. This marine species of Chrysococcus is probably nearest *C. spiralis* Lackey, but the ringed appearance of the lorica is clearly annulate here, and not spiral.

Cryptochrysis atlantica sp. nov.

Figs. 7, 8

Cellulae arcuatae, apice rotundatae, truncatae, basi acuminatae, rigidae; flagellis 2, inaequalibus ex ventrali sulco longo ascendentibus; chromatophoris 1 vel 2, luteo-viridibus, dorsalibus; stigmate nullo; plasmate hyalino granuloso; membrana glabra; cell. long. 12-15 μ, lat. 7-10 μ.

This organism occurred sparingly in several samples. It tapers to a posterior point frfom a broadly rounded anterior end, the dorsal side being convex, ventral concave, so that from a side view it is arched. On the ventral surface is a long insunk median groove from which emerge two subequal flagella. There are one or two small vesicles and a median nucleus. No stigma. There may be either one or two chromatophores, plate like, yellow-green and dorsal in position. It swims in a rapid spiral but frequently comes to rest for rather long periods. Nutrition probably holophytic. Reproduction not seen. *C. atlantica* is near *c. commutata* Pascher, but the emergence of the flagella and the location of the contractile vacuole is practically median, because the ventral groove extends so far back before the mouth region is formed.

Heteromastix fissa sp. nov.

Figs. 9, 10

Cellulae orbiculares, a latere visae ellipticae, rigidae, membrana glabra, dimidio secus longitudinem contractae; flagella 2, inaequalia; stigmata 2, anteriora; chloroplastibus singulis, magnis, cupuliformibus, viridibus, utrinque pyrenoidibus magnis, singulis munitis; long. 28 μ, lat. 25 μ.

This form is almost circular in outline, or a little broader than long. A median depression divides it into right and left halves. It is greatly flattened, hardly exceeding 8 microns in thickness. The membrane is firm and smooth. A massive bright green cup shaped chloroplast is present and there is a large basal ring shaped pyrenoid enclosed in a shell. Two subequal flagella are present but they arise separately in the right and left halves. Two stigmas are similarly located near the flagellar bases. No reproduction observed. Swimming movements not seen, since all specimens found were quiescent.

The organism was never common. A few individuals would appear in an occasional sample, in the sediment from traps as a rule but on occasion it was found in centrifuged material. The medium division and the location and separation of the flagella and stigmas are strikingly suggestive of a dividing Pedinomonas, near *P. rotunda* as described by Korschikoff from muddy pools in the Charkow region. Pedinomonas was never seen, however, and this organism occurred with sufficient frequency to indicate it was the normal vegetative state; also the organism would live several days in moist chambers, and move about, but never divide. *Heteromastix angulata* Korschikoff is common in Scioto River (Ohio) plankton; it has subequal flagella, is roughly hexagonal in outline and commonly lacks a stigma. The flagella of this marine form are almost equal, and it is not angulate. Class Chlorophyceae, Order Volvocales, Family Polyblepharidaceae.

Triangulomonas rigida gen. et sp. nov.

Figs. 11, 12

Cellulae rigidae, triangulares, a latere visae vel inferne planae vel superne modice arcuatae, apicem versus oblique truncatae; membrana crassa, dilute fusca, postice granulis longitudinaliter dispositis ornata; flagellis 2, inaequalibus, uno porrecto, altero reverso, ex ore alte excavato ascendentibus; cytoplasmate interdum sphaerico; long. 18 μ, lat. 15 μ.

This curious organism appeared on several occasions, always crawling in sediment. Its body is rigid, enclosed in a heavy membrane, and is triangular in shape. The posterior margin is rounded while the sides are slightly bowed out; the ventral surface is flat, but the dorsal surface rises to a point a short distance behind the apex, a side view showing an abrupt rise in front and a gradual curve up to this high point from the posterior margin. The membrane is slightly brown in color and several rows of punctations extend forward from the posterior margin. The color obscures most of the internal details, but the cytoplasm contains a number of spheres, possibly oil droplets. There is also a mouth-gullet-reservoir system, from which emerge two flagella, the larger trailing about one and one half times body length, the anterior one vibratile only at its tip, about as long as the cell, and tapering. No stigma; nucleus not observed.

The gullet-reservoir and the tapering flagella indicate that the organism belongs in the Euglenophyceae, but its further affinities depend on more knowledge of its pharyngeal apparatus, obscured in living specimens, as noted above. It probably belongs in the family Peranemaceae, near the curiously sculptured *Heteronema spirale* Klebs, with generic and species characteristics as illustrated.

Peranemopsis striata gen. et sp. nov.

Fig. 15

Cellulae anguste fusiformes, inferne attenuatae, superne rotundatae; metabolicae; membrana hyalina spiraliter punctulata; gula alte excavata, in vesiculam terminata; flagello singulo, longo, ad basin bacillo longo singulo praedito; cytoplasmate hyalino, granulas amylaceas paucas gerente; stigmate nullo; long. 90-110 μ, lat. 15-30 μ.

A large, free swimming or crawling Euglenid encountered a number of times. Body narrowly fusiform, but rounded in front and pointed at the posterior end. Usually enlarged at one point toward the end, as indicated by the figure, and quite metabolic at times. Because of the exceptional transparency of the cytoplasm the mouth, gullet and reservoir are easily distinguishable. Alongside, and slightly below there is a single falcate rod, enlarged anteriorly. A small nucleus is posterior and the only inclusions are a few paramylum disks. The pellicle is finely striated, spirally.

This organism was at first thought to be a Peranema. Its exceptional clearness, however, enables one to see definitely that only a single flagellum is present and there is certainly no doubt that the rod organ is single. Members of this new genus are colorless, devoid of an eyespot and have a single pharyngeal rod and would be metabolic. They would belong in the class Euglenophyceae, family Peranemaceae. Curiously enough, this species fulfills almost exactly the original description of *Peranema trichophorum* (Ehr.) Stein, which species was first shown by Hartmann and Chagas in 1910 to have two flagella.

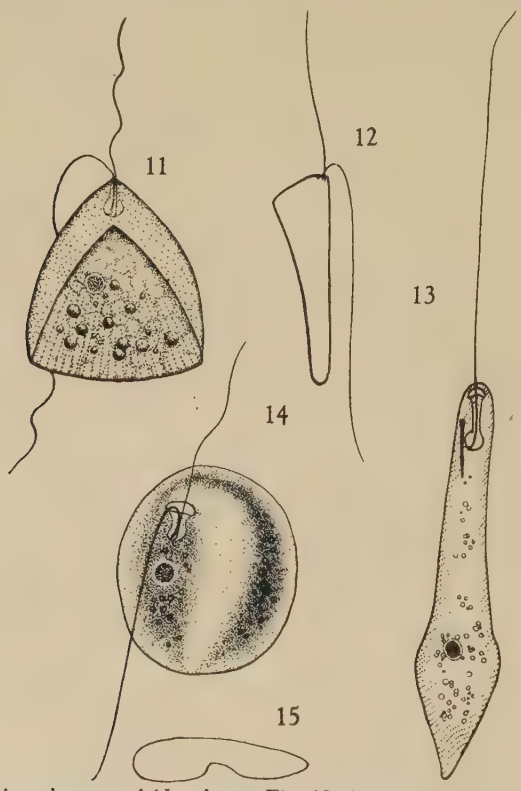


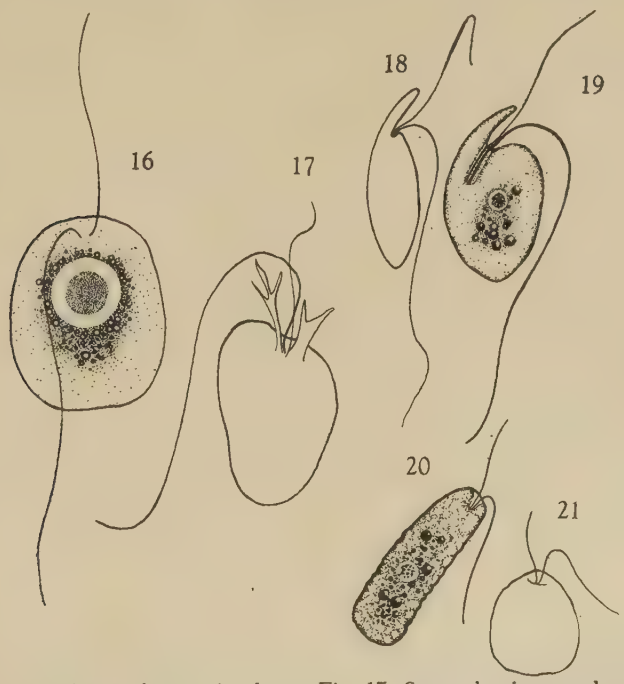
Fig. 11. *Triangulomonas rigida*, above; Fig. 12. Same, long section; Fig. 13. *Peranemopsis striata;* Fig. 14. *Anisonema orbiculatum*, above; Fig. 15. Same, x-section.

Anisonema orbiculatum sp. nov.
Figs. 14, 15

Cellulae orbiculares, a latere visae tenues, superne modice rotundatae, inferne planae, dimidio secus longitudinem valde excavatae; flagellis 2, per orem ex pharynge ascendentibus; anteriore tenui, posteriore valido, recto, retrorso; pellicula glabra; cytoplasmate minute granulato; long. 12-25 μ.

One of the commonest of all the bottom dwelling types, and quite variable in size. Circular in outline, slightly rounded above but flattened ventrally, except for a wide, rather deep groove in the median plane. There are two flagella, emerging on the left ventral side through a somwhat crescentic subterminal mouth opening into a shallow gullet. Below this also on the left side is a relatively conspicuous nucleus. The short anterior flagellum is thin, about body length; the trailer stout, about twice body length and carried straight back. No stigma or color. Numerous inclusions, mostly small spheres, in the cytoplasm. Pellicle firm, smooth. Movement prinicipally a steady glide forward. No observed ingestion of food. Reproduction not seen.

This form is close to *A. emarginatum* Stokes, but its constant orbicular shape, extreme flatness and deep ventral depression seem to indicate a valid species, especially since it was probably the most abundant Anisonema in the samples.



Figs. 16. *Bodopsis platyformis*, above; Fig. 17. Same, showing pseudopodia; Fig. 18, *Rhynchobodo agilis*, long. section; Fig. 19. Same, above; Fig. 20. *Phyllomitus salinus*, extended; Fig. 21. Same, contracted.

Bodopsis platyformis sp. nov.

Figs. 16, 17

Cellulae orbiculares vel ovales, planae, mutabiles, decoloratae; apice interdum paullo emarginatae; flagellis 2, e cavo ascendentibus, longiore retroflexo; nucleo centrali, magno, lateraliter granulato; long. 15-20 μ, lat. 12-15 μ, crass. 8 μ.

Generally round to oval in outline, but when coming to rest, slightly metabolic. A slight indentation in front serves as a mouth region, and at times a few short pseudopodia are extended from here; this is the point of emergence of the flagella. The anterior one is about body length, the trailer about two and one-half times as long. The nucleus is median, large, conspicuous, with a wide clear zone just inside its membrane. Against this membrane is an accumulation of granules and spherical bodies. Pellicle smooth. Colorless. No feeding or reproduction seen. Abundant in bottom samples at times.

The genus Bodopsis Lemm. provides for naked, free-swimming, Zoomastigoda which have a swimming and a trailing flagellum emerging from a slight anterior depression which at times also gives rise to pseudopodia. The type species *B. alternans* (Klebs) Lemm. has a posterior nucleus. The marine form corresponds well to this description, but is of different shape and has a conspicuous nucleus, anteriorly located.

Rhynchobodo agilis sp. nov.

Figs. 18, 19

Cellulae ovales, in anteriore parte processu digitiformi mobili, ad basin ejus ore pharyngis valde excavatae praeditae; flagellis, 2, uno tenui, recto, altero longo, crasso; plasmate hyalino, interdum sphaeris paucis praebenti; long. 10 μ.

Cell naked, metabolic to some extent, flattened. Oval in outline with a long finger like process in front, which is movable. At the base of this a mouth opening into a deep gullet. Two flagella emerge from this, a short, fine swimming flagellum and a heavier trailer about three times body length. Specimens treated with methyl green show a median nucleus, but neither they nor living forms show a parabasal body. Cytoplasm clear, homogeneous, except occasionally small spheres. Animals are sometimes elongate and vary somewhat in size. Reproduction by longitudinal division while active. Abundant in debris. A culture was maintained 18 months along with Spirulina. The Rhynchobodo figured here is about twice as large, more flattened, and with a much deeper mouth region than the fresh water species, *R. nasuta* (Stokes) Klebs.

Phyllomitus salinus sp. nov.

Figs. 20, 21

Cellulae mutabiles, typice cylindratae, apice truncatae, basi rotundatae, lateribus irregularibus; flagellis 2, e gula parva anteriore ascendentibus, longiore retroflexo; cytoplasmate granulato, decolorato; nucleo centrali; long. 12 μ, lat. 5 μ.

This small form is very active. Typically elongate, cylindrical, metabolic, with 2 flagella emerging from a slight anterior depression. The trailer is about two-thirds body length, the anterior one and one-half body length. Nucleus median, cytoplasm clear, granular, a few small spheres sometimes present. Nutrition and reproduction not ascertained. Very common at times. This is a much smaller form than either of the two fresh water species. It also has shorter flagella and a less pronounced mouth region. This and the preceding genus belong in the Family Bodonaceae, order Protomastiginae.

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SEDIMENTS OF BUZZARDS BAY, MASSACHUSETTS

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ABSTRACT

The modern sediments of the bay are described principally by the use of quantitative data derived from mechanical, mineralogical and chemical analyses. The environment of the sediment and its source and mode of deposition are discussed.

INTRODUCTION

This study is a part of the program of the Woods Hole Oceanographic Institution relating to the investigation of sediments of the Continental Shelf and coastal waters of the eastern United States. The field work and a part of the laboratory work were done under the auspices of the Oceanographic Institution during the summer of 1934. The remainder of the laboratory work was done subsequently in the sedimentation laboratory of the University of Chicago.

Buzzards Bay is a deep indentation of the shoreline which marks the western boundary of Cape Cod (fig. 1). The bay is 28 miles long, averages about 8 miles in width, and has an average depth of about 50 feet in its central portion. The surface area of the bay is 235 square miles, and the area of the land draining into it is 385 square miles, only 1.64 times as great. The relief of the land draining into Buzzards Bay is low, the maximum elevation in the watershed being between 200 and 300 feet. This land is gently rolling and poorly drained with numerous lakes and marshes. There is a good cover of vegetation and the soils are sandy and porous so that erosion takes place slowly.

The northwestern and northern shores are deeply indented whereas the eastern and southeastern shores are more regular. A chain of islands separated by tidal channels forms the southeastern side of the bay. The Cape Cod Ship Canal connects the head of Buzzards Bay with Cape Cod Bay to the northeast. The water in the bay has nearly the same concentration of salt as the adjacent ocean water, since tidal currents cause frequent interchange between the two bodies and there are no large streams bringing in fresh water.

The northwestern shore of Buzzards Bay represents, roughly, the edge of a shield of igneous rocks and Paleozoic sediments that constitutes the bulk of the New England Lowland. A few deep well borings show that the surface of the crystalline mass extends beneath Cape Cod to the east and south. The bed rock of the northwestern shore of Buzzards Bay is the Dedham granodiorite, upon which lies a shallow, discontinuous cover of glacial drift and recent sediment. Thick deposits of glacial drift form the other shores of the bay. A frontal moraine extends from the northeastern corner of the bay southward to Woods Hole (fig. 2), turns southwestward and forms the Elizabeth Islands that separate the bay from Vineyard Sound. It may be traced in shoals lying southwest of the islands for a distance of 12 miles. This moraine is the inner one of two prominent ridges of drift making up a large part of Cape Cod and the New England Islands.

GEOLOGIC HISTORY OF THE REGION

Nantucket, Martha's Vineyard, Block Island and Long Island mark the edge of an almost completely submerged cuesta of Tertiary and Cretaceous rocks which formerly extended farther northward and overlaid the older rocks of the mainland. The more or less continuous depression between this cuesta and the New England oldland probably was formed by subaerial erosion during a time of extreme lowering of sealevel in the late Tertiary (Veatch, 1906). Pleistocene glaciation modified the surface of the oldland to some small degree and formed the system of moraines and outwash plains which constitute the bulk of Cape Cod and the New England Islands. In late Pleistocene time, the sea was perhaps as much as 200 feet below its present level when the glacial ice disappeared from southern New England. The bottoms of Buzzards Bay and similar features must, therefore, have been exposed to subaerial processes for at least a short time.

TOPOGRAPHY OF THE BOTTOM

The bottom topography (fig. 2) when considered in detail is irregular and reflects the effects of glaciation. Submerged ridges parallel to the Elizabeth chain apparently are poorly developed recessional moraines. Certain details of topography, such as the deep channel leading seaward from the mouth of the bay and the extension of the 40-foot contour toward the head of the bay, may have resulted from the late glacial subaerial erosion.

The greater part of the bay is less than 50 feet deep, but a depression near Quicks Hole attains a depth of 126 feet and channels in the mouth of the bay contain depths of 100 to 140 feet. The

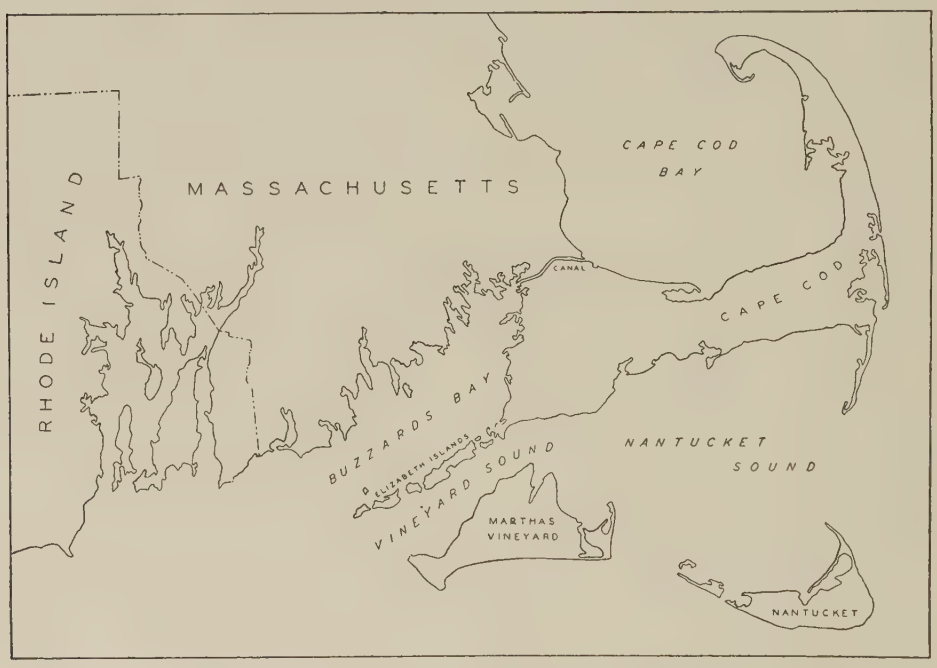

FIG. 1.—Index map showing location of Buzzards Bay.

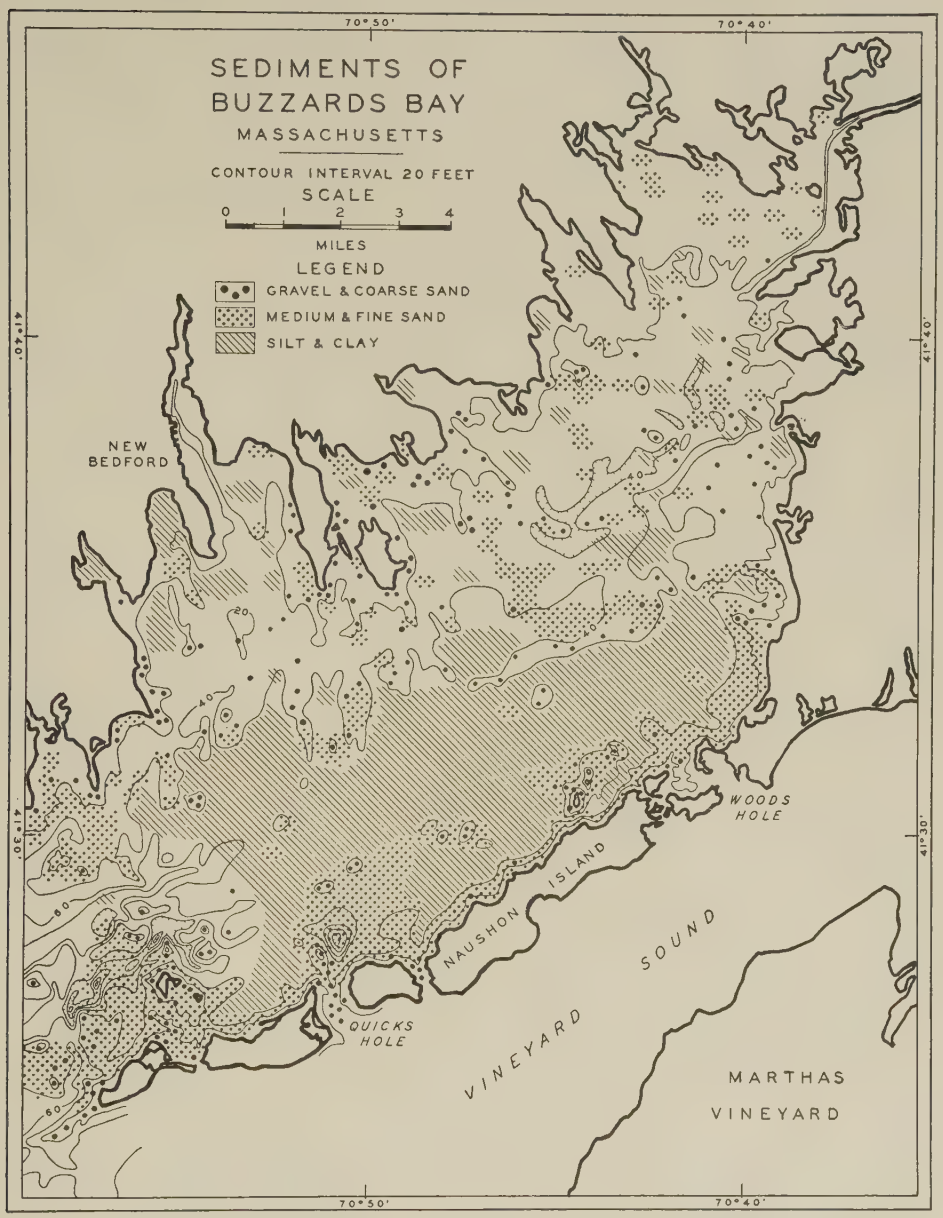

FIG. 2.—Sediments of Buzzards Bay. Shoreline and topography based on U. S. Coast & Geodetic Survey Chart No. 249, July, 1933.

low ridges forming the promontories of the northwest shore are roughly parallel to the direction of ice-movement during glaciation. At the head of the bay these ridges trend southeastward whereas at the mouth of the bay they trend nearly

southward. An orientation roughly normal to the line of the moraine on the opposite side of the bay is thus maintained. Shoals in the northwestern side of the bay mark the extensions of the ridges under water.

FIELD METHODS

Field work was done from the *Asterias*, a 40-foot power boat of fisherman type owned by the Oceanographic Institution. Bottom sampling apparatus consisted of coring tubes, a clamshell snapper and a Stetson-Iselin sampler (Hough 1939).

Two hundred and twenty-five samples were taken, most of them serially along lines crossing the bay at intervals from near its head to its mouth. In running these lines, departure was taken from some fixed point such as a buoy. The distance between stations was measured by taking the travel time of the boat which was operated at a constant speed between stations, and the lines were terminated at some other fixed point. In most of the series, the distance between samples was one-half mile. Coarse-grained sediments were stored in glass jars and cores of fine-grained sediments were wrapped in newspapers.

LABORATORY METHODS

The mechanical composition of the sediments was studied by the sieving (Wentworth, 1926) and the pipette (Krumbein, 1932) methods. The sieves used were graduated on the basis of the square root of 2. The weight percentages of material in the different size grades were calculated as cumulative percentages, and cumulative curves were drawn from which the first quartile (Q1), median (M) and third quartile (Q3) diameters were read. The statistical constants devised by Trask (1932) for sorting and skewness were then calculated for each sample. The sorting factor, So., equals $\sqrt{Q3/Q1}$ and the skewness, Sk., equals $Q1 \times Q3/M2$. In these equations Q3 is greater than Q1. The log of the skewness (to the base 10) is used in presenting the data. The results of the mechanical analyses are given in table 1.

In making a mineralogical study, small-sized separates of one size-grade common to several samples were obtained by use of a miniature sample-splitter of the Jones type (Otto, 1933). Separation into light and heavy fractions was then made with bromoform of specific gravity of 2.76. The fractions were mounted on microscope slides in piperine. This medium was used because its index of refraction falls near the center of the range of the indices of the heavy minerals. The minerals were identified by a petrographic microscope, and their frequencies were determined by counting the number of each species found in making three or four traverses on each slide. Between 100 and 300 grains were counted in each slide.

The acid-soluble material (assumed to be largely calcium carbonate) was determined by weighing the dried material, treating it with dilute hydrochloric acid (1:4), filtering, drying, and reweighing.

Data on the organic content of the sediments were supplied by H. R. Seiwell, chemist of the Woods Hole Oceanographic Institution, who made the determinations on samples which he collected for the purpose.

BOTTOM SEDIMENTS

The sediments of Buzzards Bay range from black, fine silts to clean, washed gravels and boulders. Cumulative curves of all the sediments analyzed were plotted on one graph. This showed a more or less regular gradation from fine-grained, rather poorly sorted sediments to coarse-grained, well sorted sediments. Since there is no distinct grouping of the samples into types, an arbitrary separation is made on the basis of the Wentworth classification. Gravel and coarse sand (median diameter greater than 0.500 mm.) are grouped together, sands of medium and fine grade (median diameter 0.500 to 0.061 mm.) are placed in a second group and silts and clays (median diameter less than 0.061 mm.) form a third. The distribution of these three groups in the bay is shown in figure 2.

TABLE 1. *Mechanical composition of sediments of Buzzards Bay, Massachusetts*

Sample No.	Latitude	Longitude	Depth in feet	Statistical constants Diameters in mm. Q1	Med.	Q3	So.	Log Sk.	Remarks
1	41°39′08″	70°45′07″	19	.170	.250	.360	1.456	−.010	
2	39′08″	44′47″	22	.142	.211	.310	1.478	−.004	
3	39′08″	44′07″	24	.185	.280	.490	1.628	+.064	
4	39′09″	43′28″	23	.260	.382	.560	1.470	.000	
5	39′10″	42′48″	19	.381	.586	.985	1.605	+.038	
6	39′11″	42′08″	25	.010	.047	.111	3.263	−.286	
7	39′12″	41′30″	42	.211	.413	.680	1.794	−.077	
8	39′12″	40′51″	30	.180	.302	.537	1.726	+.026	
9	39′09″	40′22″							Hard Bottom
10	38′47″	40′48″	29	.182	.381	.610	1.828	−.116	
11	38′24″	41′13″	33	.203	.428	.710	1.870	−.104	
12	37′54″	42′00″	42	.051	.366	.645	3.560	−.595	
13	37′58″	42′22″	18	.439	.579	.724	1.280	−.022	
14	38′08″	42′37″	26	.325	.510	.745	1.512	−.031	
15	38′50″	44′24″	28	.187	.286	.438	1.530	−.001	
16	38′20″	44′18″	30	.231	.337	.457	1.410	−.032	
17	37′49″	44′14″	29	.050	.302	.480	3.100	−.582	
18	37′18″	44′08″	36	.239	.321	.437	1.353	+.004	
19	36′22″	43′48″	31		>.500				*
20	35′55″	43′38″	38		<.061				*
21	35′27″	43′27″	39		>.061				*
22	35′00″	43′17″	38		>.061				*
23	34′32″	43′07″	39	.195	.267	.362	1.360	−.005	
24	34′05″	42′56″	33		>.061				*
25	33′52″	42′46″	41		>.061				*
26	33′22″	42′37″	46		<.061				*
27	32′53″	42′25″	46		<.061				*
28	32′24″	42′12″	42		<.061				*
29	31′55″	41′59″	34	.105	.241	.410	1.980	−.130	
30	35′30″	40′09″	28						Hard Bottom
31	35′17″	40′40″	39	.283	.482	.661	1.530	−.094	
32	34′43″	41′44″	45	.005	.014	.042	2.920	.000	
33	34′26″	42′18″	37		<.500				*
34	34′17″	43′33″	36		<.500				*
35	34′30″	44′09″	41		<.500				*
36	35′02″	40′10″	51	.006	.021	.051	2.890	−.135	
37	34′45″	40′11″	33		<.500				*
38	34′34″	39′51″	28	.354	.592	.968	1.654	−.010	
39	34′38″	39′32″	38	.350	.567	.910	1.612	−.004	
40	34′45″	39′11″	36	.325	.714	1.425	2.092	−.040	
41	34′07″	40′24″	41		<.500				*
42	41°33′08″	70°40′59″	46		<.061				
43	32′10″	41′34″	38		<.500				*
44	33′47″	42′23″	46		<.061				
45	33′28″	41′48″	49	.006	.018	.049	2.780	+.004	
46	33′11″	41′14″	47		>.061				*
47	32′54″	40′38″	37		>.061				*
48	32′44″	40′19″	33		>.061				*
49	32′36″	40′04″	30		>.061				*
50	36′44″	47′31″	23	.200	.255	.323	1.270	−.002	
51	36′15″	47′12″	29	.219	.300	.409	1.370	−.002	
52	35′52″	46′45″	37		.110	.246			*
53	35′28″	46′14″	37	.212	.326	.483	1.510	−.015	
54	35′05″	45′53″	37	.276	.426	.617	1.490	−.030	
55	34′42″	45′26″	39	.258	.404	.616	1.540	−.057	

* Determinations by partial analysis and inspection.

Sample No.	Latitude	Longitude	Depth in feet	Statistical constants Diameters in mm. Q1	Med.	Q3	So.	Log Sk.	Remarks
56	34′19″	45′00″	43	.230	.352	.556	1.550	+.013	
57	33′56″	44′34″	43	.202	.334	.530	1.620	−.020	
58	33′33″	44′08″	45	.005	.010	.020	2.078	−.020	
59	33′08″	43′42″	46	.004	.008	.017	2.130	−.012	
60	32′46″	43′16″	47		<.074				*
61	32′22″	42′50″	45		.181				*
62	31′58″	42′23″	35	.222	.433	.791	1.890	−.024	
63	31′41″	41′42″	35	.178	.245	.345	1.391	+.009	
64	31′28″	41′39″	24						Gravel
65	34′51″	48′36″	28	.121	.200	.300	1.580	−.043	
66	34′31″	48′10″	28	.240	.377	2.310	3.100	+.591	
67	34′10″	47′45″	36	.177	.305	.490	1.660	−.031	
68	33′06″	46′22″	44		<.074				*
69	32′44″	45′55″	46		<.074				*
70	32′22″	45′29″	46		<.074				*
71	32′00″	45′02″	47		<.074				*
72	31′38″	44′35″	48	.222	.295	.426	1.380	+.037	
73	33′49″	50′19″	34	.125	.177	.254	1.420	+.005	
74	33′25″	49′54″	48		.165	.262			
75	33′02″	49′29″	30	.515	.670	.985	1.380	+.053	
76	32′38″	49′02″	47	.007	.020	.049	2.690	−.087	
77	32′16″	48′37″	49	.005	.014	.035	2.626	−.056	
78	31′52″	48′12″	51	.005	.016	.037	2.615	−.107	
79	31′29″	47′47″	48	.008	.024	.053	2.624	−.163	
80	30′44″	46′53″	45	.006	.025	.055	2.940	−.253	
81	30′20″	46′28″	45		<.061				*
82	29′57″	46′03″	48	.007	.024	.050	2.630	−.200	
83	29′34″	45′36″	30	.015	.077	.240	4.050	−.226	
84	31′30″	47′18″	48		<.061				*
85	31′47″	46′46″	46	.007	.021	.042	2.440	−.180	
86	31′53″	46′12″	47		<.061				*
87	32′14″	44′24″	48		<.061				*
88	41°31′53″	70°54′27″	40						Gravel
89	31′53″	53′46″	32	.043	.228	.480	3.340	−.390	
90	31′52″	53′04″	46		<.061				*
91	31′52″	52′20″	47	.008	.029	.059	2.710	−.252	
92	31′52″	51′38″	37	.024	.115	.222	3.060	−.397	
93	31′51″	51′17″	47	.045	.158	.254	2.400	−.345	
94	31′55″	50′44″	47	.121	.176	.247	1.428	−.017	
95	32′02″	50′31″	25						One pebble
96	32′07″	50′19″	40	.167	.217	.307	1.355	+.037	
97	31′35″	50′07″	46		<.061				*
98	31′22″	49′30″	54		<.061				*
99	30′09″	48′53″	50		<.061				*
100	30′58″	48′04″	47		<.061				*
101	31′01″	47′31″	46		<.061				*
102	31′03″	46′53″	46		<.061				*
103	31′06″	46′17″	46	.005	.014	.037	2.690	−.020	
104	31′09″	45′40″	48	.050	.202	.370	2.720	−.343	
105	31′12″	45′05″	46	.178	.353	.579	1.800	−.080	
106	31′13″	44′47″	42	.215	.315	.468	1.480	+.006	
107	31′14″	44′29″	41	.223	.295	.407	1.350	+.018	
108	31′19″	43′57″	28	.187	.341	.550	1.710	−.051	
109	31′25″	43′17″	43		<.061				*
110	31′27″	42′57″	44		<.061				*
111	31′30″	42′37″	39		.062	.238			*
112	31′32″	42′17″	44	.155	.230	.308	1.410	−.045	
113	30′17″	45′40″	45		<.061				*
114	30′36″	45′06″	46	.005	.014	.038	2.700	+.004	

Sample No.	Latitude	Longitude	Depth in feet	Statistical constants Diameters in mm. Q1	Med.	Q3	So.	Log Sk.	Remarks
115	30′37″	47′54″	46	.016	.041	.070	2.060	−.188	
116	30′04″	47′19″	38	.012	.038	.066	2.320	−.250	
117	29′43″	46′56″	43	.009	.036	.060	2.580	−.370	
118	29′22″	46′34″	45	.008	.032	.055	2.720	−.377	
119	29′11″	46′23″	18	.172	.422	1.195	2.640	+.065	
120	31′00″	50′23″	56	.009	.030	.069	2.840	−.173	
121	30′52″	49′59″	56	.011	.039	.079	2.680	−.246	
122	30′36″	49′27″	52	.025	.080	.110	2.100	−.367	
123	30′18″	48′57″	51	.029	.089	.123	2.052	−.342	
124	30′00″	48′27″	48	.013	.051	.087	2.770	−.362	
125	29′42″	47′57″	44	.009	.035	.066	2.740	−.314	
126	29′24″	47′27″	46	.032	.147	.382	3.450	−.248	
127	29′05″	46′56″	42	.049	.135	.251	2.260	−.172	
128	30′33″	50′27″	56		<.061				*
129	30′07″	50′35″	56		<.061				*
130	29′41″	50′42″	54		<.061				*
131	29′15″	50′49″	51		>.061				*
132	28′49″	50′56″	51		>.061				*
133	41°28′23″	70°51′03″	63	.218	.320	.520	1.540	+.045	
134	27′59″	51′09″	80	.176	.256	.480	1.650	+.110	
135	27′57″	51′04″	100	.137	.431	.818	2.440	−.219	
136	28′10″	50′52″	79	.201	.287	1.370	2.610	+.526	
137	28′23″	50′40″	68	.164	.210	.318	1.390	+.072	
138	28′36″	50′28″	53	.114	.158	.189	1.290	−.063	
139	29′02″	50′05″	53		>.061				*
140	29′27″	49′39″	52		>.061				*
141	29′49″	49′15″	53		>.061				*
142	30′20″	48′51″	51						See Table 3
143	27′47″	51′08″	62	.198	.262	.350	1.330	+.005	
144	27′54″	50′48″	122	.182	.254	.520	1.690	+.165	
145	28′00″	50′29″	80	.152	.198	.265	1.319	+.012	
146	28′06″	50′10″	54	.100	.138	.180	1.340	−.025	
147	27′22″	48′40″	18						Gravel
148	27′36″	48′49″	25	.162	.200	.294	1.348	+.075	
149	27′51″	48′58″	39	.040	.078	.120	1.730	−.104	
150	28′19″	49′17″	39	.037	.080	.117	1.780	−.172	
151	27′35″	50′58″	66	.205	.725	4.116	1.418	+.207	
152	27′27″	50′40″	54	.148	.188	.250	1.300	+.019	
153	27′13″	50′51″	52	.165	.245	.427	1.608	+.069	
154	27′02″	50′55″	45						Gravel & shells
155	26′52″	50′52″	38						Gravel & algae
156	26′35″	50′52″	38						Gravel & shells
157	26′13″	50′40″	45						Gravel, shells & algae
158	26′03″	50′25″	40						Sand & shells
159	25′56″	50′05″	47						Sand & shells
160	31′00″	54′45″	60	.012	.044	.173	3.880	+.008	
161	30′50″	54′40″	30						Hard bottom
162	30′44″	54′40″	9						Hard bottom
163	30′36″	54′36″	20	.035	1.156	2.900	2.880	−.120	
164	30′29″	53′56″	52		<.061				*
165	30′22″	53′15″	52		<.061				*
166	30′13″	52′33″	57		<.061				*
167	30′00″	51′12″	56		<.061				*
168	30′24″	54′25″	39	.302	.575	1.045	1.860	−.020	
169	30′02″	54′02″	53		<.061	.068			*
170	29′40″	53′40″	63		<.061	.098			*
171	28′56″	52′56″	58		<.061	.102			*
172	28′34″	52′34″	57		<.061	.070			*

Sample No.	Latitude	Longitude	Depth in feet	Statistical constants Diameters in mm. Q1	Med.	Q3	So.	Log Sk.	Remarks
173	28′11″	52′11″	56		<.061	.084			*
174	27′44″	51′45″	28	.187	.287	.417	1.494	−.051	
175	27′36″	51′34″	33	.109	.144	.177	1.272	−.031	
176	27′30″	51′52″	61		<.061				*
177	27′18″	52′27″	48		<.061				*
178	27′05″	53′03″	44		<.061				*
179	26′53″	53′39″	39		<.061				*
180	26′26″	54′15″	20	.277	.467	.890	1.190	+.054	
181	26′20″	55′40″	18						Pebbles, sand & shells
182	30′35″	55′14″	40	.035	.200	.455	3.600	−.400	
183	30′05″	55′12″	53	.016	.034	.095	2.420	+.111	
184	31′25″	55′30″	38	.092	.332	.620	2.600	−.287	
185	31′05″	55′48″	48	.154	.282	.426	1.660	−.081	
186	30′41″	56′08″	50	.033	.148	.328	3.180	−.311	
187	30′16″	56′29″	38	.131	.253	.485	1.920	−.004	
188	29′52″	56′51″	36	.339	.462	.602	1.330	−.020	
189	29′13″	57′22″	28						(1st trial) 1 pebble
190	29′13″	57′22″	30	.190	.310	2.800	3.830	+.771	(2nd trial)
191	28′39″	57′12″	84	.010	.040	.121	3.405	−.112	
192	28′11″	57′02″	101	.026	.102	.281	3.260	−.146	
193	27′44″	56′52″	57	.311	.451	.628	1.421	−.011	
194	27′30″	56′47″	83	.172	.305	.526	1.750	−.011	
195	27′15″	56′42″	82	.297	.490	.922	1.765	−.058	
196	26′47″	56′32″	50	.185	.320	.605	1.805	+.095	
197	26′19″	56′22″	45	.130	.220	.414	1.780	+.045	
198	27′02″	57′10″	145	.145	.262	.371	1.600	−.104	

It may be seen that the coarser sediments generally occur in exposed areas near shore and on topographic highs. The finer sediments occur in the deeper south-central portion of the bay and in the protected embayments of the northwest shore. The deep holes in the mouth of the bay and the depression near Quicks Hole contain coarse sediment and, therefore, present a special problem.

The relation between median diameter of the sediment and depth of water was investigated by plotting these two figures for each sample on a graph. No significant degree of correlation was found. Differences in the degree of exposure to wave and current action on the irregular bottom are believed to be of greater importance than absolute depth in determining the characteristics of the sediments.

The sorting factor was plotted against median diameter in a graph (fig. 3), which indicates clearly the tendency for the finer sediments to be poorly sorted and the coarser sediments to be well sorted.[1] This graph shows a concentration of points between the sorting values 2.5 and 3.0, below a median diameter value of 0.061 mm. Another group of points is located between the sorting values 1.35 and 2.00 above the median diameter value 0.130 mm. There are no sediments with a median diameter less than 0.061 mm. having sorting factors less than 2.00, and comparatively few of

[1] On the basis of 170 samples of marine sediments, Trask set up the following classification of sorting: well sorted sediments are those with So. less than 2.5, normally sorted sediments are those with So. between 2.5 and 4.5, and poorly sorted sediments are those with So. greater than 4.5. (Trask, 1932, p. 72) Stetson gives an average of 1.45 for well-sorted, near-shore marine sediments. (Stetson, 1937)

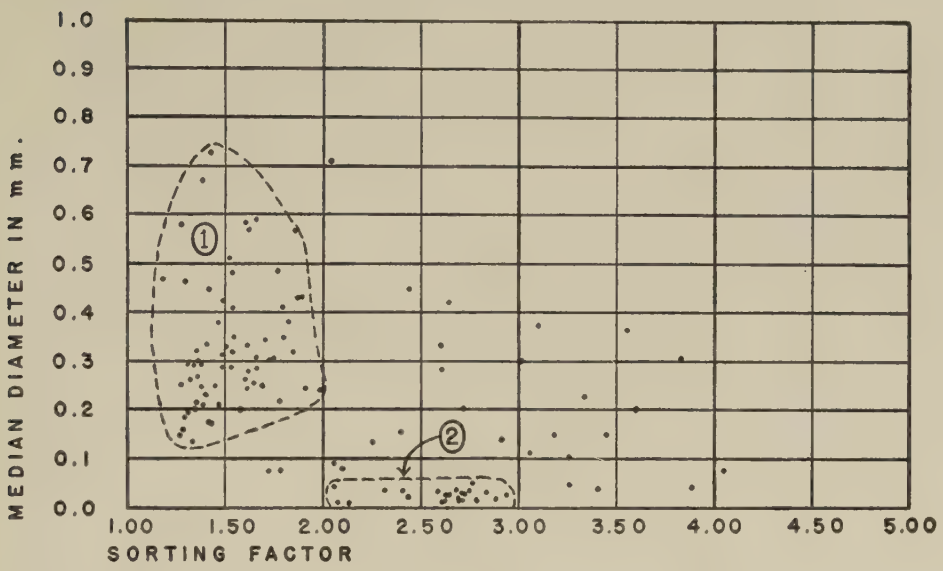

FIG. 3.—Graph of median diameter plotted against sorting factor.

the coarser sediments have sorting factors greater than 2.00.

The log of skewness was plotted against median diameter in another graph (fig. 4). This shows a group of points between the median diameter values 0.130 and 0.600 mm. having logs of skewness not exceeding plus or minus

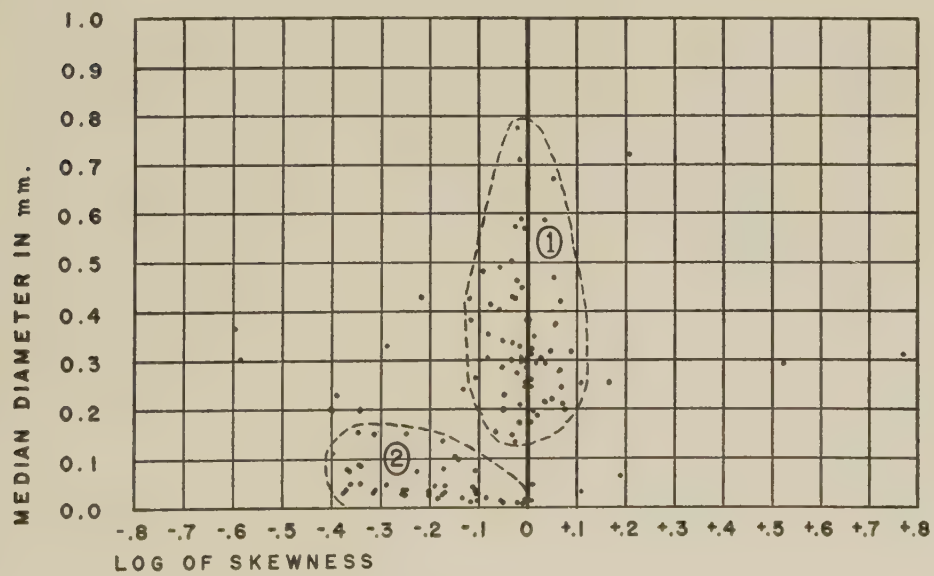

FIG. 4.—Graph of median diameter plotted against logarithm of skewness.

0.12, and being about equally distributed on either side of skewness log zero. A few of the coarser sediments are widely scattered on the graph. These are the same samples which have sorting values greater than 2.00 in figure 3. Practically all of the remaining samples fall into a group with median diameters less than 0.160 mm. and logs of skewness from zero to minus 0.40.

The deep hole in the bay north of Quicks Hole channel (fig. 2) contains sand having a median diameter of 0.254 mm. in its deepest part where the depth is 126 feet. No sediment finer than about 0.200 mm. median diameter was found in the depression, but in many places outside this area, in less than 60 feet of water, sediment of less than 0.061 mm. median diameter was found. Quicks Hole channel is floored with an erosion resisting pavement of coarse gravel and organic growth (mainly calcareous algae and hydrozoa) while the shoal extending northward from the west side of Quicks Hole to Lone Rock is composed of gravel and coarse sand with a large amount of shell material. Between Lone Rock shoal and the bottom of the 126-foot depression the sediment decreases in grain size but maintains its clean-washed, oxidized appearance and its high shell content. The strong tidal currents of Quicks Hole pouring into Buzzards Bay seem to be directly related to this distribution of sediment. It is not possible to assign the origin of the depression to scouring by the tidal current, but the current apparently is responsible for the non-accumulation of fine-grained sediment.

Some of the closed depressions in the submerged channels in the mouth of Buzzards Bay also contain coarse sediment. Sand with a median diameter of 0.262 mm. is present at a depth of 140 feet in one of these holes. The reason for this occurrence is less clear than in the depression adjacent to Quicks Hole. However, it seems probable that the islands and numerous gravel covered shoals in the mouth of the bay produce a concentration of tidal flow sufficient to cause appreciable current velocity at the bottoms of some of the depressions.

MINERALOGICAL COMPOSITION

Nine samples were selected for mineralogical study. Six of these[2] were taken along a line crossing the bay at a right angle to its axis between Wilkes Ledge[3] and Quicks Hole. The remaining three samples[4] were taken on the sides of the deep hole north of Quicks Hole. The grade between 0.104 and 0.208 mm. was studied because all nine samples contained material in this range. No far-reaching conclusions can be drawn from the study of a single arbitrarily chosen grade, but the data indicate which minerals are present and permit certain generalizations to be made.

Quartz is the most abundant mineral in all of the samples. Orthoclase and plagioclase feldspars are second in abundance in most of the samples. The light fractions contain, besides the minerals just mentioned, a few Foraminifera, Ostracoda and fragments of Hydrozoa.

The heavy minerals identified in the samples are listed in table 2 with figures showing relative abundance. The most abundant heavy minerals are aragonite, opaque metallics, hornblende and muscovite. Brown tourmaline is present in small amounts in all the samples studied. The aragonite is organic in origin and represents fragments of animal tests. Biotite evidently is undergoing alteration from an original state in which its color is brown to a product which possesses a green color and is nearly isotropic in character. A few grains were observed which were partly brown and unaltered and partly green and nearly isotropic. Rare grains with a green color showing compound polarization were identified as glauconite, and, in the light of Galliher's work (1935), are believed to repre-

[2] Sample Nos. 163, 168, 170, 171, 173 and 175.

[3] Position, 41° 30′ 45″ N., 70° 54′ 40″ W., shown in figure 2 as a gravel covered shoal.

[4] Sample Nos. 143, 145 and 153.

sent the end product of alteration of the biotite. The opaque metallic minerals are largely magnetite, but include a small percentage of ilmenite and opaque brown constituents. The garnets are mainly salmon-colored, but a few colorless (bluish-colored in piperine) grains of the mineral occur. The zircons are bluish-purple in color, and most of them are well-defined crystals. Altered minerals include various light-colored opaque or translucent grains.

The amount of micaceous minerals, muscovite, biotite and altered biotite, present in the heavy fractions of the one size-grade studied, varies roughly as an inverse power function of the median diameter of the sample. These minerals make up only 3.8 per cent of the heavy fraction of the 0.104–0.208 mm. grade in a sample having a median diameter of 0.575 mm., whereas they constitute 84.9 per cent of the corresponding part of a sample having a median diameter of 0.050 mm. The great abundance of the micaceous minerals in the coarser fractions of the fine-grained, mid-bay sediments can be explained on the basis of their low hydraulic values (or small equivalent diameters) relative to those of the more spherical grains occurring in the same sediment.

TABLE 2. *Mineralogical composition of heavy fraction of 0.104–0.208 mm. grade, in nine samples of sediment from Buzzards Bay, Massachusetts**

Mineral	Sample number								
	163	168	170	171	173	175	143	145	153
	%	%	%	%	%	%	%	%	%
Aragonite	54.4	7.2	1.5	1.5	3.8	9.2	10.3	.9	11.9
Biotite (brown)	.8	—	4.4	5.1	3.8	4.5	1.0	6.7	—
(green)	1.6	4.1	14.8	20.1	16.8	5.3	3.4	1.7	2.8
Calcite	—	—	—	—	—	3.8	1.5	—	6.3
Chlorite	3.6	1.1	1.5	.7	.8	9.2	1.5	2.5	2.8
Enstatite	—	2.0	.7	—	.7	—	1.5	3.4	—
Epidote	3.2	—	7.4	.7	1.5	3.8	9.3	8.4	6.6
Ferrous metallics	13.9	44.4	4.4	.7	.8	6.9	17.1	25.1	27.9
Garnet	2.4	7.2	.7	—	—	.8	2.5	3.4	4.9
Glauconite	—	—	—	—	—	2.3	2.5	—	—
Hornblende	6.7	17.5	5.9	1.5	2.3	16.0	4.4	11.8	5.6
Kyanite	—	1.1	.7	—	—	—	—	—	.7
Muscovite	6.4	4.1	40.6	57.3	53.4	5.3	6.9	5.9	5.9
Olivine	—	—	—	—	—	—	1.0	—	—
Sillimanite	.4	—	—	—	.7	5.3	3.4	.9	2.4
Titanite	.4	1.0	—	.7	.8	—	1.5	1.7	.4
Topaz	1.6	—	—	—	—	.8	.5	—	1.0
Tourmaline	1.2	1.0	2.2	.7	.8	2.3	4.4	5.0	3.5
Zircon	.8	3.0	—	.7	—	—	—	2.5	1.4
Zoisite	—	—	—	—	—	—	.5	—	.4
Altered	2.0	5.1	9.5	2.3	9.2	12.2	11.2	4.1	7.7
Miscellaneous	.8	1.1	5.9	8.1	4.6	12.2	15.6	16.0	7.7
Heavy minerals in grade; % by weight	14.0	16.7	1.9	3.5	5.8	1.7	3.1	3.5	3.4
Depth of water in feet	20	39	63	58	56	33	62	80	52
Median diameter in mm.	1.156	.575	.061	.061	.061	.144	.262	.198	.245

* Refer to table 1 for location.

Localities favorable to the growth of shell-secreting organisms have bottom sediments containing much shell material. When shells occur in a situation where wave action is of importance, they are broken and much of the carbonate material is incorporated as sedimentary grains and finds a place in the regular size distribution of the sands. In the deeper waters of the bay where fine-grained sediment is accumulating, the shells are not mechanically broken and they occur as erratic particles of relatively large size and do not form a part of the regular size-distribution curves.

TABLE 3. *Acid-soluble material in sample no. 142,* Buzzards Bay, Massachusetts*

Depth in core	Acid-soluble material
Cm.	*Per cent*
0– 5	3.24
5–10	3.13
10–15	2.92
15–20	2.37
20–25	2.32

* Refer to table 1 for location.

In order to determine the variation in amount of acid-soluble material with depth in the sediment, a core sample (no. 142) of the fine-grained deposit in the south-central part of the bay was divided into sections of 5 cm. each, and a representative part of each section was treated with acid. Table 3 gives the results of this study. There is a small but continuous decrease in amount of acid-soluble material from top to bottom of the core. Stratification of this deposit is indicated partly by variation in quantity of shells. The recognizable layers have an average thickness of about 1.5 cm., but, as described below, these layers may include one or several years' contribution of sediment. Thus the 5 cm. sections may represent the accumulations of several years. The decrease in amount of carbonate with depth in the core must be due either to a long time trend in amount of carbonate deposited or to a slow solution of the carbonate. The shells in the deeper layers of several core samples examined are thin, lacking in lustre, and are structurally weakened thus showing the effects of solution.

ORGANIC CONTENT

The organic content of the fine-grained sediments of the bay averages about 2 per cent, as determined in analyses of 20 samples by Seiwell. The fine-grained material with this organic content possesses a black color when wet and a dark grey color when dry. In order to determine whether such a deposit might be a source sediment of petroleum, a calculation was made of the probable oil yield of the deposit.

Using Trask's data on oil yield of organic sediments (1932, p. 40), it may be calculated that one cubic foot of the fine-grained Buzzards Bay sediment could yield 0.07 cubic foot of oil. The area covered by the fine-grained sediment is roughly 100 square miles. A layer of sediment 10 feet thick in this area would have a volume of 28 billion cubic feet. At the rate of 0.07 cubic foot of oil per cubic foot of sediment, this deposit would produce 1,960,000,000 cubic feet or 350 million barrels of oil. It is thus seen that the fine-grained sediment of Buzzards Bay might be a source sediment of petroleum at some time in the future.

STRATIFICATION

Distinct stratification shown by variations in grain size or in shell content was observed in many of the core samples of fine-grained sediment. Freshly collected cores were laid horizontally on a table and sliced longitudinally by pushing a knife through them in a direction normal to the length of the core. Thin layers of fine sand were detected by prodding the exposed faces with a needle. Shells were located by carefully separating one of the halves of each core with a needle.

The layers observed were approximately 1 to 2 cm. thick. It is impossible

to say whether these layers represent annual deposits of sediment. An estimate can be made of the maximum thickness annual layers could have in the bay, as follows: the probable maximum depth that the bay could have had in any considerable area in its south-central part is 100 feet, a figure obtained by comparison of the topography of the bay with that of the adjacent Vineyard Sound and ocean floor. If the original depth were 100 feet, and the average present depth in the area of fine-grained sediment is taken as 50 feet, then a deposit of sediment 50 feet thick has been laid down. The minimum length of time during which water surface has been at or near its present level is taken as 10,000 years, the approximate period elapsed since withdrawal of the glacial ice from the area. Assuming that 50 feet of sediment were laid down in 10,000 years, the average thickness of one year's deposit is 1.5 mm. If compaction is taken into account, the surface layers of the deposit would have a thickness somewhat greater than this. Considering the grain size of the deposit, it is estimated that the porosity in its lower part would be about 35 per cent and the porosity in the upper 25 cm. would be about 65 per cent. The layers in the upper 25 cm. would have a thickness of about 2.3 mm.

The average thickness of the layers observed in the core samples is 1.5 cm., about 6.5 times as great as the calculated maximum possible thickness of annual layers. The discrepancy may be explained in two ways. (1) The thickness of observed layers may represent more than one year's deposit. This is possible if the coarser grains and the concentrates of shells observed in the cores represent unusual conditions occurring only once in several years. (2) The rate of accumulation of sediment may be greater at present than during most of the life of the bay. This is possible because the rate of erosion of the watershed probably has been increased materially by cutting of forests and cultivation of the soil.

INTERPRETATIONS

Sources of sedimentary material.—Because of its abundance and unconsolidated character, glacial drift is by far the most important source of sedimentary material. The constituents of the drift were derived from the land to the northwest, as shown by the fact that Dedham granodiorite is the most common type of rock present. In texture the drift is coarse; grains in the sand sizes are most abundant and little silt or clay is present. The Dedham granodiorite of the northwestern shore is comparatively very resistant to erosion; therefore, the amount of material it contributes directly is small. The mineralogy of the bay sediments is related to that of the granodiorite and indicates an ultimate origin in that rock mass.

A considerable amount of calcium carbonate is contributed to the sediments of the bay by shell-secreting organisms. Whole shells and shell fragments occur in abundance at the surface of the deposits, but solution of the carbonates apparently is taking place in the deposit so that they do not represent a permanent contribution of great importance.

Wave action.—The storm waves and swells of the open ocean reach only a short distance into the bay, because of the protection afforded by the islands and shoals at its mouth, but waves generated within the bay attain a considerable size. The more exposed shores of the bay show abundant evidence of wave attack in their low cliffs and boulder-strewn beaches. It is difficult to judge the intensity of wave action on the bottom of the bay. Coarse sediment occurs on topographic highs in as much as 40 feet of water. This coarse concentrate may have developed largely during a time of lowered sea level and since that time have been kept free of fine sediment and organic matter by gentle bottom currents. However, wave action at a depth of 40 feet in a body of water the size of Buzzards Bay should be capable of producing

the concentrate observed, since Kindle (1925) reports the destruction by wave action of a staunch vessel and the removal of its 75 tons of coal while sunk in 65 feet of water in Lake Ontario.

Tidal currents.—In the channels between the islands of the Elizabeth chain, the tidal currents have maximum velocities of 4 to 6 knots at the surface, and currents near the bottom in the center of the bay have maximum velocities of 0.5 knot.[5] Coarse sediment is transported in the tidal channels between the islands, but only fine silt and organic matter are carried into the central part of the bay.

Ice rafting.—During the colder winters a large amount of ice forms in the bay and in the adjacent sound. It is swept through the tidal channels and ground against the shores by the tidal currents. Some sedimentary material may be transported by the ice and rare particles of coarse sand and gravel occurring in the fine-grained sediments may have been contributed in this manner.

Change in topography of the bay.—The bay shores, subject to the most violent erosive action, have undergone little change in shape. Headlands and island shores have been cut back several feet. Many indentations have been reduced in curvature and some have been nearly closed off by deposition of sand and gravel, but the net change in configuration of the shore lines has been small. The presence of abundant boulders in the glacial drift results in the formation of a boulder pavement on the beaches that is very resistant to erosion.

The bottom topography has been rendered more gentle by erosion of the shoals and deposition in most of the hollows, but the shoal areas, like the beaches, are protected by coarse concentrates and, therefore, waste slowly. The greatest change in topography seems to have taken place in the central part of the bay where accumulation of fine-grained sediment has produced a gently sloping floor.

[5] Current velocities determined by the U. S. Coast and Geodetic Survey. The data were taken from unpublished records obtained from the Survey through the courtesy of R. S. Patton, director.

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Contribution No. 215

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Oceanography

Season of 1938

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OCEANOGRAPHY

The Grand Banks Region, Labrador Sea, and Davis Strait in 1938

By Floyd M. Soule [1]

On March 23, 1938, the *General Greene* departed from Woods Hole, and, after stopping at Halifax with parts for the patrol cutters, proceeded to the Grand Banks of Newfoundland to take up her duties as oceanographic vessel of the International Ice Patrol Force. As a part of this work a current survey was begun on March 31, at station 2541 located at 43°34′ N., 53°45′ W. During the month of March the reported positions of ice indicated that the major branch of the Labrador Current shifted from the abnormal course along the Avalon Peninsula of Newfoundland to the normal course along the eastern edge of the Grand Banks. However, as there was a possibility that some berg ice had drifted south from Cape Race prior to the shift, and because surface temperature reports indicated the presence of large quantities of Labrador Current water south and southwest of the Tail of the Grand Banks, it seemed desirable to investigate the current situation in the southwestern sector on this first survey. Accordingly, the work of collection of data progressed from the position of the first station given above southeastward around the Tail and then northward along the eastern edge of the Banks.

Excellent conditions of wind, sea, and visibility held from the beginning of the station work until April 7, on which date conditions got progressively worse and, after completion of station 2582 in latitude 44°24′ N., longitude 49°32′ W., the vessel was hove to at 2140 in a blinding snow driven by a force 7 wind accompanied by a rough sea. After 40 hours, during which the vessel had been blown about 100 miles south-southeastward, conditions had improved sufficiently to proceed toward the next station where the work of collection of data was resumed at 0600 on April 10 under unfavorable conditions, which again grew worse. Station work was completed at station 2590 located at 44°52′ N., 46°46′ W., on April 11, a total of 50 stations having been occupied. As the time during which the vessel had been hove to on the 8th and 9th had been applied in working up the data collected prior to that time, the current map was soon completed and ready for delivery on April 11, although the patrol cutter *Tahoe* could not be reached until 1010 on April 12. Having delivered the current chart aboard the *Tahoe*, the *General Greene* then proceeded to St. John's, where she arrived on April 13.

[1] Contribution No. 215 of the Woods Hole Oceanographic Institution.

For the purpose of making a second current survey the *General Greene* departed from St. John's on April 26. As anticipated from the previous survey, ice had been reported drifting westward of the Tail of the Grand Banks and therefore it was considered advisable to include this region, about as far west as longitude 52° W., in the second survey. In order to cover this area, the survey could not extend farther north than about latitude 46° N., on the eastern edge of the Banks.

Accordingly, the work of collection was begun at station 2591 located at 46°27′ N., 48°56′ W., and progressed from north towards south. No considerable interruption to the work was experienced, and collection of data was completed at station 2649 at 43°36′ N., 51°28′ W., on May 7, a total of 59 stations having been occupied. The resulting current map was then constructed, and although it was completed 11 hours after the last station, it could not be delivered until after the *Tahoe* could be contacted on the morning of May 8. After the current map had been delivered aboard the patrol cutter, the *General Greene* proceeded to St. John's, arriving there on May 9.

The *General Greene* departed from St. John's on May 23 to make a third current survey of the Grand Banks region. The ice distribution indicated the desirability of current information from the region between Flemish Cap and the Grand Banks, and as the previous survey showed the Labrador Current extending westward of the Tail of the Grand Banks, the desirability of information from this area was also indicated. The survey was planned, therefore, to extend from about latitude 47° N., to and somewhat westward of the Tail. Advice had also been received that during the summer concerted investigations of the Atlantic current northwest of the Azores would be undertaken by other vessels. As the circulation in the North Atlantic has much to do with ice movements in the vicinity of the steamer lanes and is believed to have an even greater effect on the quantity of ice to drift into menacing positions it seemed worth while to extend the section running south from the Tail of the Banks sufficiently to cross the Gulf Stream so that this section might ultimately be studied in connection with conditions prevailing the same year farther eastward. With these considerations in mind the work of collection of data was begun at station 2650 located at 47°09′ N., 48°38′ W., the survey progressing without incident from north towards south. The work of collection of data was completed at station 2731 at 42°00′ N., 50°56′ W., on June 6, 82 stations having been occupied. The resulting current map was then constructed and delivered aboard the *Tahoe* 13 hours after the station work had been completed. The *General Greene* then returned to St. John's, where she arrived on June 8.

On June 20 the *General Greene* departed from St. John's to make a fourth current survey. In order to satisfy a request for immediate

information regarding the currents south of the Tail of the Grand Banks the survey was begun at the southern end of the area and proceeded from south toward north. The work of collection of data began at station 2732 located at 43°30′ N., 50°13′ W., and, continuing without incident, was completed at station 2808 at 47°20′ N.,47°15′ W., on July 3, a total of 77 stations having been occupied.

As soon as possible after completing the stations south of latitude 43° N., the currents in this vicinity were mapped and the situation was described to the patrol cutter by radio. It should be remarked here that in spite of an unusually high percentage of fog experienced during this survey, occasional sights and sounding fixes at fortunate times and intervals served to locate the stations with sufficient accuracy to produce a map of average reliability. The current map was delivered aboard the patrol cutter *Tahoe* 15½ hours after completion of the work of collection of data. The *General Greene* then proceeded to St. John's, arriving there on July 4.

Thus a total of 268 oceanographic stations were occupied during the ice patrol season. From July 22 to August 17 an additional 39 stations were occupied during a post-season cruise in the Labrador Sea and Davis Strait. These stations were disposed in the form of three sections, namely, (*a*) from South Wolf Island, Labrador, to Cape Farewell, Greenland, (*b*) a longitudinal section from section (*a*) to Davis Strait Ridge, and (*c*) on Davis Strait Ridge from the "west ice" to Holsteinsborg, Greenland. In addition to the usual temperature and salinity observations, samples were collected for the determination of dissolved helium and oxygen from the deeper levels at the stations forming section (*b*) and from three stations in the middle of section (*a*). The temperature, salinity, and oxygen data collected at the 307 oceanographic stations occupied during the season and on the post-season cruise are presented in the oceanographic table in this bulletin.

On the post-season cruise 451 sonic soundings were made with the fathometer along the above-mentioned sections. These soundings have been corrected for sounding velocity by means of the concurrently collected temperature and salinity data in accordance with the temperature-salinity-pressure-velocity relations given in the British Admiralty tables (H. D. 282). The corrected soundings have been tabulated and supplied to the United States Hydrographic Office and to the International Hydrographic Bureau. In addition to these soundings a continuous sonic sounding section was made along the continental shelf from Davis Strait to the Strait of Belle Isle. This section was incidental to ice observation along the route and was intended to shed light on the question of whether or not any submarine canyons of the type found in other parts of the world exist in the Labrador shelf. The best location for such a section would have been

near the edge of the shelf. Because of other considerations, however, this section was located near the middle of the shelf. No canyons were found to intersect this section but because of its location all that can be said is that if canyons do exist on the Labrador shelf they do not extend as far as the line of this section. Other incidental data collected on the *General Greene*, both during the season and post-season cruises, consisted of barograms and sea-water surface thermograms.

The equipment and methods of measurements were the same as in 1937. Routine salinity bridge measurements and calibration titrations were performed by the oceanographer's assistants, Bernard S. Loebig, yeoman, first-class, and James F. Flannery, seaman, first-class. Other assistants in the observational work were Thomas C. Crabe, yeoman, third-class, and William George, seaman, first-class.

At the 268 stations occupied during the season the extent and nominal depths of the serial observations of temperature and salinity were the same as during the season of 1937 except that at the stations comprising the section across the Gulf Stream occupied during the third survey the observations extended to a depth of between 2,000 and 2,500 meters. On the post-season cruise the temperature and salinity measurements extended to as near bottom as was practical at most of the stations. In general the oxygen samples were taken at depths from 100 meters down and the helium samples only in the deeper layers, from 400 meters down.

As a check on the functioning of the reversing thermometers, a program of intercomparison through periodic shifts in thermometer pairs was carried out as in previous years. A total of 1,735 individual comparisons were investigated. The probable differences between the corrected readings of a pair of thermometers varied among the different groups from 0.003° to 0.017° C. and the probable difference for the entire 1,735 comparisons was 0.010° C. An additional 267 comparisons were made in which one thermometer of the pair was unreliable. The probable difference for these 267 comparisons was 0.034°C. However, as the readings of these thermometers were known to be unreliable they were not used in determining the observed temperatures which are considered to be accurate to 0.01° C.

Near the end of the season a progressive error in the standardization of the salinity bridge was suspected. This was later verified by the careful titration of 38 actual sea-water samples from various depths. The tabulated values of salinity have been corrected for this error, the original measurements before correction being too low by the following amounts: Second survey 0.019‰; third survey, 0.029‰; fourth survey and post-season cruise, 0.054‰. As these corrections are equivalent to differences in dynamic height of 14, 21, and 39 millimeters when referred to the 1,000-decibar surface and are, for practical

purposes, constant for any one survey, the current maps are presented as originally drawn with the reference surface given in the title differing

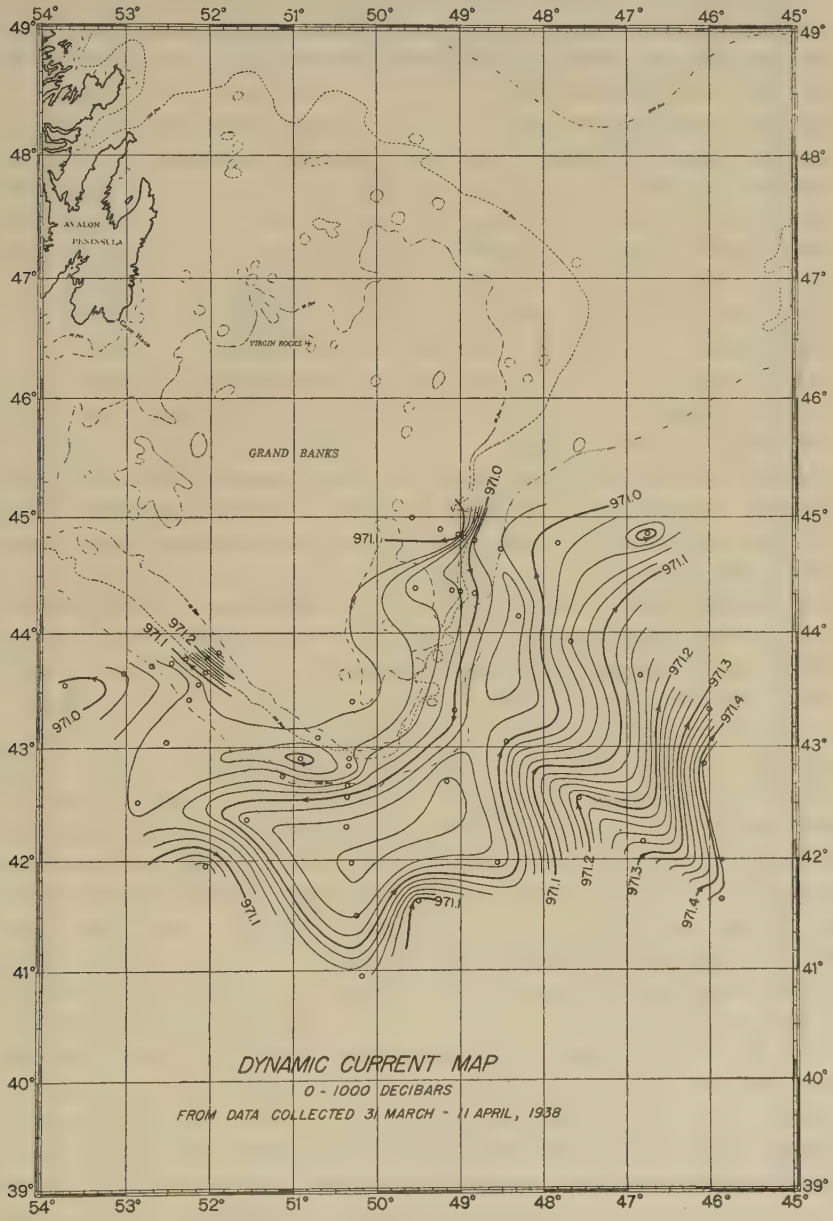

FIGURE 45.—Dynamic current map, from data collected March 31–April 11, 1938.

by the appropriate amounts from the nominal value of 1,000 decibars. The current maps prepared during the season were made following the procedure used in the past several years. The map representing

current conditions on the post-season cruise is referred to the 2,000-decibar surface.

In figure 45 is shown the current map resulting from the first survey, March 31 to April 11. Because of the adverse conditions under which they were occupied, the two northeasternmost stations of this map are considered to be less reliable than usual. The rest of the map, however, is considered to be of average reliability and agreed in detail with the sets experienced by the surveying vessel. An unusual feature is the complicated pattern introduced by the clockwise whorl centered at about 43° N., 51° W. This may possibly have resulted from the March gales. Whatever the cause, the pattern did not persist. The high velocity on the southwestern edge of the Banks at about longitude 52° W., is apparently unrelated to the Labrador Current moving south along the eastern edge of the Banks, but perhaps is connected with the western branch of the Labrador Current which, earlier in the year, brought an abnormal proportion of the ice past the Avalon Peninsula. Another unusual feature shown in this map is the westward fanning of the Labrador Current between the forty-fourth and forty-fifth parallels. This gives an indication of the source of the growlers reported in on the Banks in this vicinity. It will be noted that this fanning occurred over the shoalest part of the Banks and may have resulted from a more effective stirring from the March gales here than in the deeper water. It is not surprising, in view of the early date of the observations, that the Grand Banks whorl is conspicuous by its absence, since it has been assumed in the past that this whorl is energized, at least in part, by differential vernal warming of the waters over the shoal. The margin of the Atlantic Current is seen to be flowing in strength although no considerable tendency toward westward intrusion was apparent. The pools of mixed water south and southeast of the Banks were larger than usual and indicated the possibility of ice drifting as far west as about longitude 52° W., should any bergs survive long enough to make the journey.

Figure 46 shows the current map resulting from the data collected on the second survey, April 27 to May 7. This map shows the Labrador Current flowing in a broader than usual path and extending westward of the Tail of the Banks about as far as during the first survey. The Gulf Stream southwest and south of the Tail moved in nearer to the Banks and decreased the size of the mixed water pool. In the eastern part of the map the Atlantic Current is seen to have been flowing with strength and although it is frequently characteristic that as the season progresses the Atlantic Current intrudes westward toward the Banks as a salient in about latitude 45° N., any advance shown in figure 46 as compared with figure 45 was very slight and was more in the shape of a broad front. Attention is called to the east-

ward diversion of a part of the Labrador Current in about latitude 45° N., and to the unusual breadth of the Labrador Current southeastward of latitude 46° N., longitude 48° W. A review of the 15 surveys

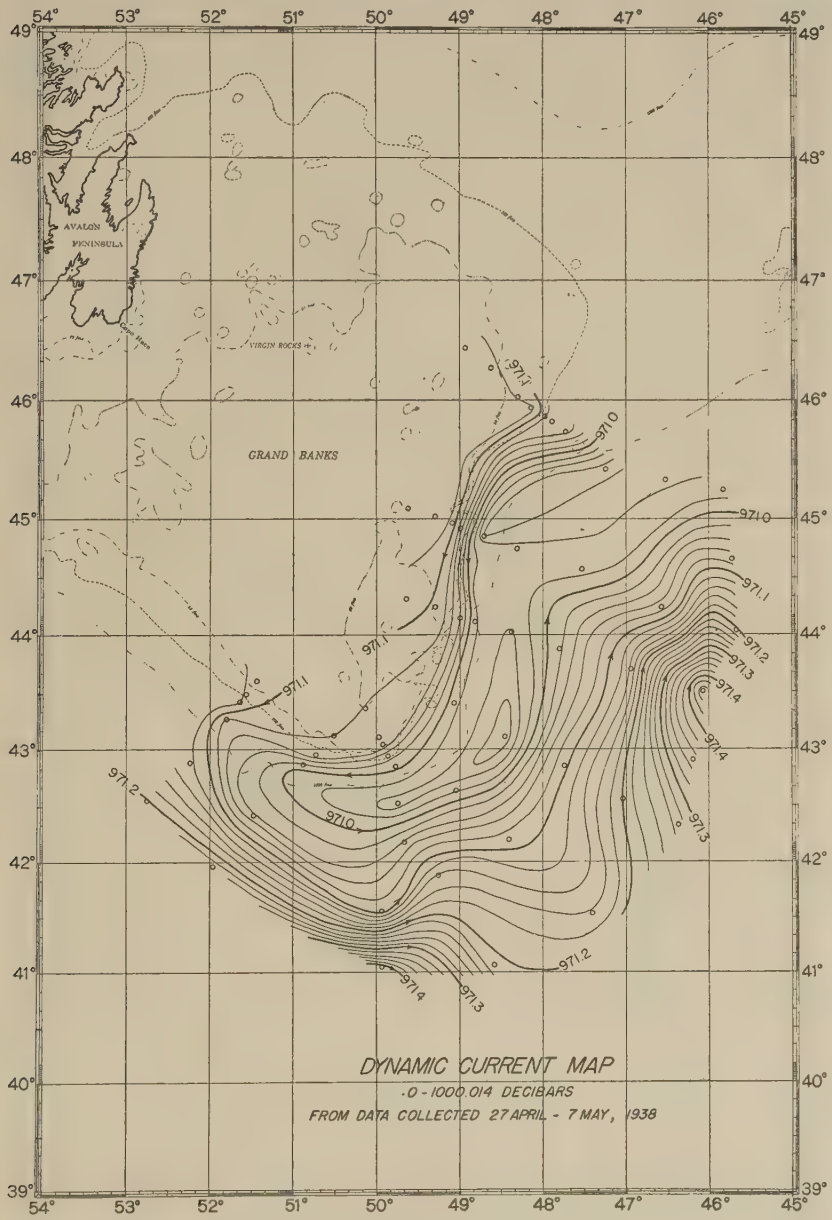

FIGURE 46.—Dynamic current map, from data collected April 27–May 7, 1938.

of this region which have been made over the period from 1932 to 1937, inclusive, reveals that one of the most constant features is that the position 46° N., 47° W., lies close to the axis of dead water between

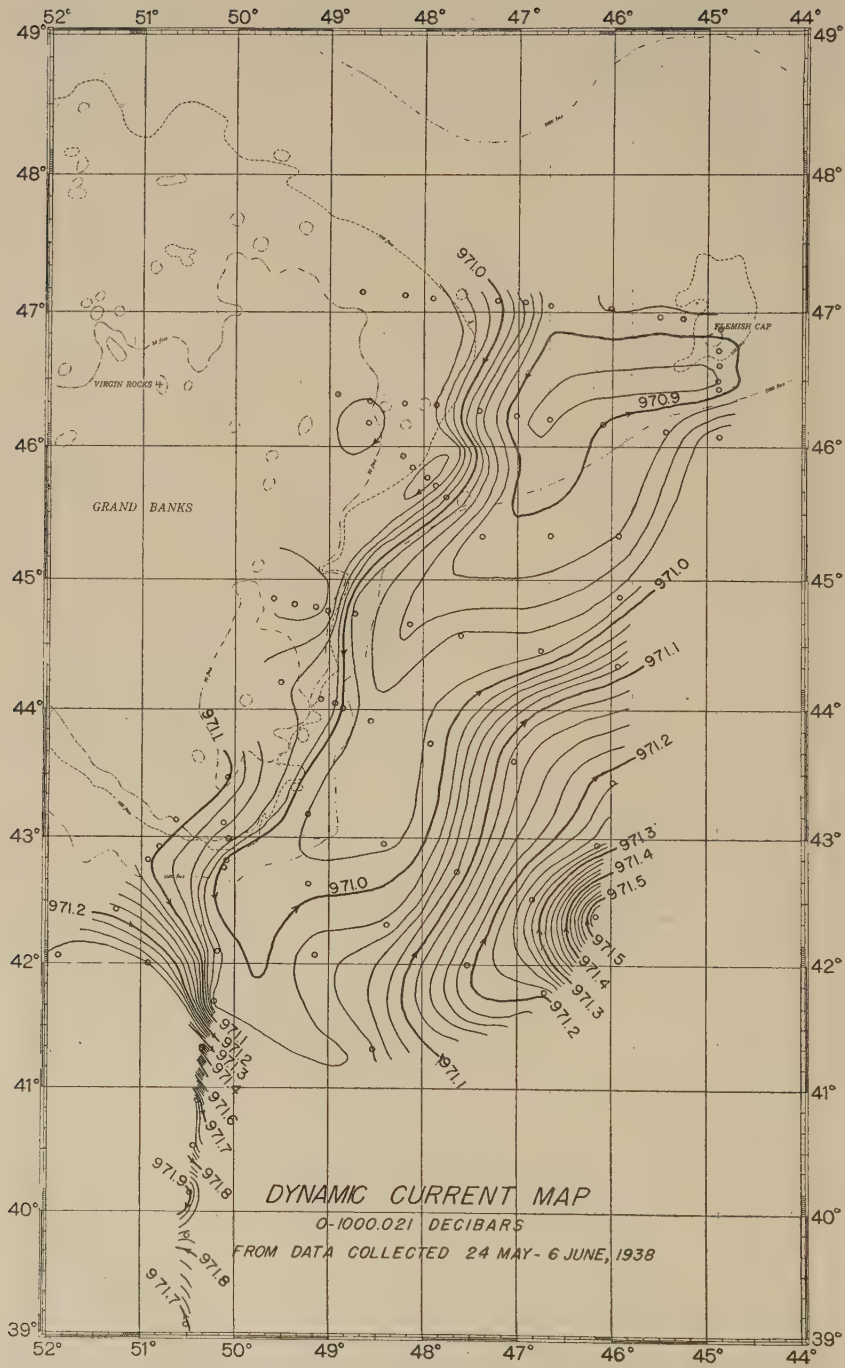

FIGURE 47.—Dynamic current map, from data collected May 24–June 6, 1938.

the southerly flowing Labrador Current on the one side and the northeasterly flowing return on the other side. It is a feature probably resulting from the bottom configuration which in this region is dominated by a relatively high ridge extending southwestward from Flemish Cap. The fact that abnormally high temperatures and salinities were found pressing close in toward the Banks in latitude 45° N., leads to the conclusion that this unusually wide southwesterly current is made up partly of true Labrador Current and partly of mixed water detached as a whorl from the border of the Atlantic Current.

The results of the third current survey, May 24 to June 6, are shown in figure 47. This map again shows the Labrador Current to have been flowing in unusual width, especially north of latitude 46° N., but only a small part of it seems to be identified with the vortical center usually associated with Flemish Cap. Between latitudes 46° N., and 44° N., a large proportion of this stream recurved northeastward, and south of latitude 45° N., some of it was deflected southwestward into the shallow water over the Banks leaving only a comparatively narrow deep water band in which bergs could travel southward toward the United States-European steamer tracks. However, the current situation at the Tail of the Banks was such that any bergs reaching that far were in favorable positions to accomplish unusually extended southward drifts. Two weak clockwise whorls near the edge of the Banks in about latitude 46° N., were associated with the eastward bulge in the Labrador Current which contributed to the effectiveness of the Atlantic Current in deflecting the large part of the Labrador Current northeastward. This part of the Atlantic Current intruded, as in the previous survey, not as a salient but as a broad front. The Grand Banks whorl, although weak, was definitely present.

Figure 48 shows the current map resulting from the fourth survey, June 21 to July 3. The map shows the triangular shaped pool of mixed water south of the Tail of the Banks. The circulation was counterclockwise around this pool except at the northeastern end where there was a slight indication of eastward movement as part of the Labrador Current recurved northeastward. Subsequent berg movements, however, seemed to show that the 971.0—decibar isobath of the pool should have been connected with the similar isobath farther north. At the southwestern corner of the map the Gulf Stream is seen to have been flowing south-southeastward and in the southeastern part of the map the Atlantic Current was intruding deeply toward the Tail of the Banks and then bending sharply east-northeastward. The Labrador Current was apparently wider south of latitude 45° N., than at the time of the third survey, even considering that a part of the western edge of this band was water contributed

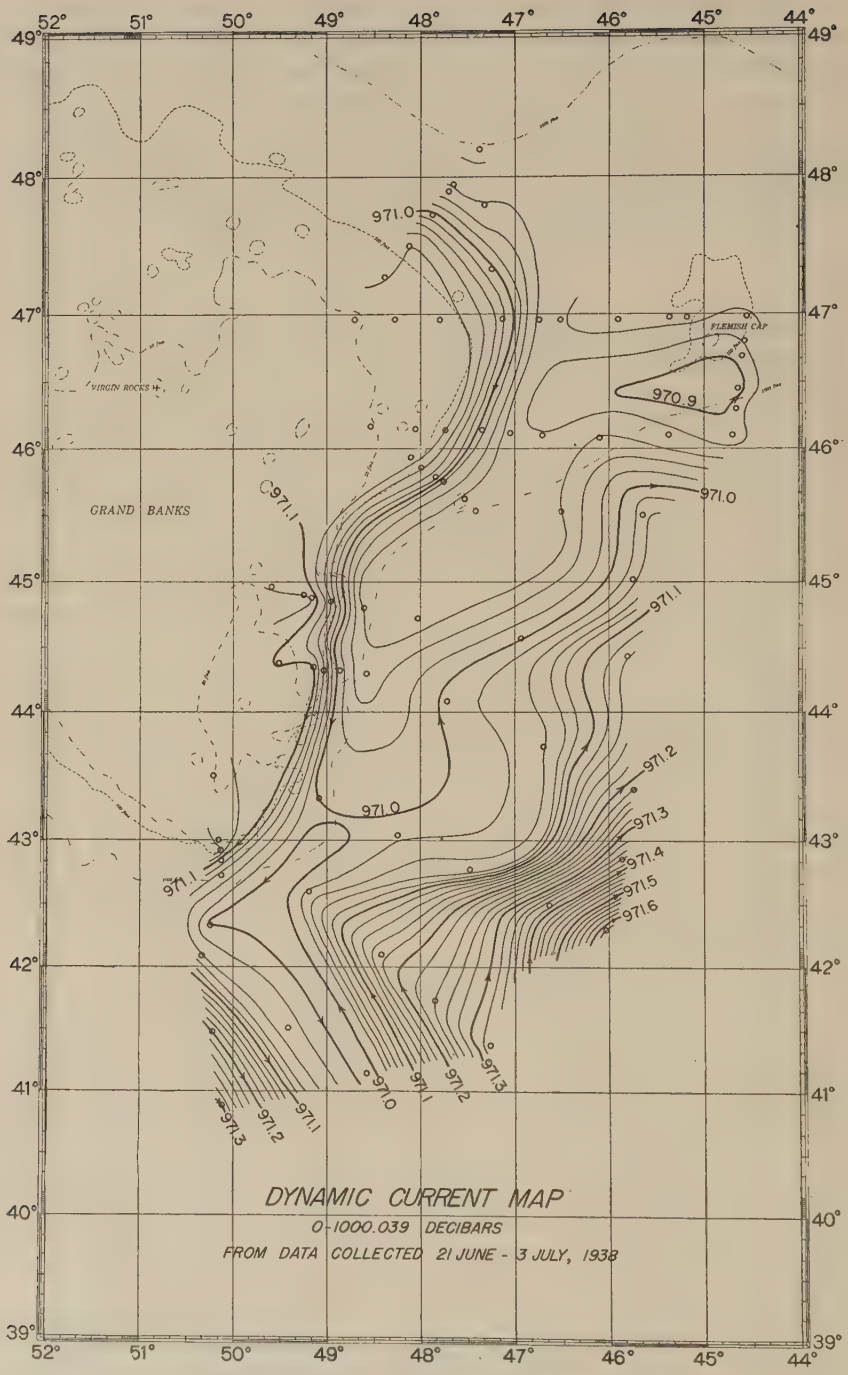

FIGURE 48.—Dynamic current map, from data collected June 21–July 3, 1938.

eastward off the Grand Banks. The weak clockwise whorls previously found near the edge of the Banks in about latitude 46° N., had been dissipated, leaving the area between the 50- and 100-fathom curves and between latitudes 46°00′ N., and 47°30′ N., very nearly motionless. Eastward of this area of quiet water, the Labrador Current showed the same unusual breadth found during the third survey.

In previous bulletins of this series the seasonal variations in the Labrador Current in the Grand Banks sector have been discussed with especial reference to the seasonal maximum in volume of flow which occurs in the month of May. The sections which have been repeatedly occupied and which form the basis of the discussions are as follows: Section T, running southeasterly from about 46°20′ N., 49°00′ W.; section U, running east and west at about the forty-fifth parallel; and section W, running south off the Grand Banks in about longitude 50° W. During 1938 section T was reoccupied three times and sections U and W were reoccupied four times each. The volume of flow, mean temperature, and minimum observed temperature were investigated for each occupation of these sections and the results are tabulated below along with similar results for all occupations of these sections from and including 1934.

TABLE 1.—*Showing volume of flow in million cubic meters per second, mean temperature in °C., and minimum temperature in °C., of the Labrador Current in the Grand Banks region*

	Mar. 16 to Apr. 15			Apr. 16 to May 15			May 16 to June 15			June 16 to July 15		
	Vol.	Mean temp.	Min. temp.	Vol.	Mean temp.	Min. temp.	Vol.	Mean temp.	Min. temp.	Vol.	Mean temp.	Min. temp.
Section T:												
1934				1.8	1.53	−1.66	1.5	2.6	−1.72	1.5	3.3	−1.70
1935				2.1	1.67	−1.71						
				4.1	2.85	−1.56	2.71	2.06	−1.50			
1936	1.86	0.98	−0.75	3.23	1.83	−0.43	3.15	2.90	−1.47			
1937				3.53	1.83	−1.49	1.96	1.55	−1.22	1.88	2.19	−1.25
1938				6.70	4.26	−1.79	3.88	1.85	−1.67	4.30	1.74	−1.62
Average	1.86	0.98	−0.75	3.58	2.33	−1.44	2.64	2.19	−1.52	2.56	2.41	−1.52
Section U:												
1934				3.48	1.11	−1.37	3.11	1.56	−1.70	0.84	1.32	−1.65
1935	3.7	2.0	−1.66	5.92	0.98	−1.24	4.46	1.75	−1.28			
1936	7.20	2.31	−0.82	6.69	1.06	−0.94	3.90	3.14	−1.23			
1937	3.54	1.54	−1.29	5.80	1.90	−1.56	2.29	1.72	−1.29	3.02	1.81	−1.41
1938	5.62	2.16	−1.20	6.34	5.66	−0.71	5.14	3.80	−1.43	4.78	1.87	−1.64
Average	5.02	2.00	−1.24	5.65	2.14	−1.16	3.78	2.39	−1.39	2.88	1.67	−1.57
Section W:												
1934				1.17	1.19	−1.15	1.63	1.07	−1.58	0.86	4.35	1.68
1935	1.08	2.72	−1.12				3.87	1.47	−1.02			
1936				3.13	2.61	0.02						
				8.78	2.85	0.08						
1937	0.54	0.66	−0.29	5.48	2.33	−0.99				3.40	2.53	−0.76
1938	5.44	3.78	−0.83	5.78	4.75	0.39	2.76	3.73	1.18	5.07	2.42	−1.59
Average	2.35	2.39	−0.75	4.87	2.75	−0.33	2.75	2.09	−0.47	3.11	3.10	−0.22

An inspection of table 1 shows that during 1938 the volume of flow was greater than the 5-year average at each occupation of each section and that the mean temperature was higher than average except for the third and fourth occupations of section T and the fourth occupa-

tion of section W. The seasonal variation in the volume of flow past sections T, U, and W during the 1938 season is shown graphically in figure 49. From this figure it will be seen that the pronounced seasonal maximum noted in other years again occurred about the beginning of May in 1938.

In continuing the inquiry into the departures from average conditions along the common boundary between the Labrador and Atlantic Currents the course of the horizontal projection of the zero salinity anomaly line in the axis of the intermediate anomaly maximum was investigated for each of the four surveys made during the 1938 season. On the first three surveys the line was entirely outside the limits of the survey except the extra-southerly section of the third survey. Only the fourth survey showed the line within the area surveyed and then only in the southeastern part of the area. This indicates that Labrador Current water was present in unusual abundance during the 1938 season and the indication is borne out by the above-mentioned fact that the volume of flow of the Labrador Current was greater than the 5-year average at each of the sections investigated.

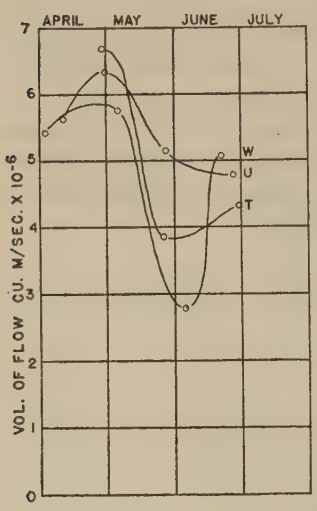

FIGURE 49.—Variation in the volume of flow of the Labrador Current in the Grand Banks region during the 1938 season.

As noted previously, during the third current survey a section was run south from the Tail of the Grand Banks near the 50th meridian to about latitude 39° N. This section was intended to cross not only the Labrador Current but also the major part of the Gulf Stream. An inspection of the surface current map for that survey (fig. 47) indicates that the section extended far enough south to include what was either a portion of the branch of the Gulf Stream that bends back toward Bermuda or part of a large vortex. An inspection of the temperature-salinity correlation at the various stations of this section when compared with earlier results from the Sargasso and from near the Azores shows this section to have negative salinity anomalies. This may be interpreted as indicating that this section did not completely cross the Gulf Stream, or that different T–S relations existed at the different times, or that a difference in standardization in the salinity determinations existed. The previously mentioned predominance of water of negative salinity anomalies, and the standardization error which was discovered and corrected lead to the opinion that a combination of the last two interpretations is

correct and that the section did cross the Gulf Stream and a portion of that branch which recurves toward Bermuda.

Investigation of the volume of flow past this section was undertaken. As described in Bulletin No. 27 of this series, there is evidence that the depth of the motionless surface is greater beneath the Atlantic Current in the vicinity of the Grand Banks than beneath the Labrador Current and that this depth is about 2,000 or 2,500 meters. Accordingly, the investigation of the volume of flow past this section was based on a reference surface of 2,000 decibars. A velocity profile was constructed and the volume of flow computed by the numerical method was checked graphically by planimeter measurements on the velocity profile. The eastward transport past the section amounted to 58.6 million cubic meters per second, of which 21.7 million returned westward past the southern part of the section between stations 2715 and 2713. This large eastward volume of flow substantiates, as does the depth of the 10° isotherm (820 meters at station 2715), the opinion that this section completely crossed the Gulf Stream. It is of interest to note that the eastward-moving water was transferring heat at the rate of 760 million cubic meter degrees Centigrade per second at a mean temperature of 12.96° C.

It is characteristic of the northern border of the Atlantic Current that the upper layers are more uniform, vertically, in temperature and salinity in that part of the current of higher dynamic height (right hand) than the upper layers in that part of the current of lower dynamic height (left hand). Because of the nonlinear relation between temperature and density it has been noted that adiabatic mixture of water masses of different temperature-salinity characteristics results in a greater density than the mean density of the masses before mixture. Thus if a storm passes over an area having the temperature and salinity distribution described above, and if that storm mixes the upper layers of the different parts of the area uniformly, it will result theoretically in the lower dynamic heights being lowered more than the higher dynamic heights are lowered and the surface velocities being increased by the resulting increase in gradient. Now it is also characteristic of the northern border of the Atlantic Current that the less uniform upper layers of the left-hand side of the current have a steeper vertical density gradient than the more uniform upper layers of the right-hand side. It is qualitatively known that the effective depth of mixing produced by a given storm is much less in surface layers of high vertical stability than where that stability is low. This conservation of water-mass identity by vertical stability results in selective mixing which will reduce the differential lowering of the lower dynamic heights which would be produced by uniform mixing and might even reverse the effect and produce a decrease in the horizontal gradient of dynamic height. The writer is not aware

of any quantitative information regarding the degree of protection against vertical mixing afforded by steep vertical density gradients near the surface.

It is of interest, then, to examine the magnitude of the effect of uniform mixing of the upper layers under such conditions of distribution, if such uniform mixing were possible. For illustration, the actual section across the Gulf Stream located at about the fiftieth meridian

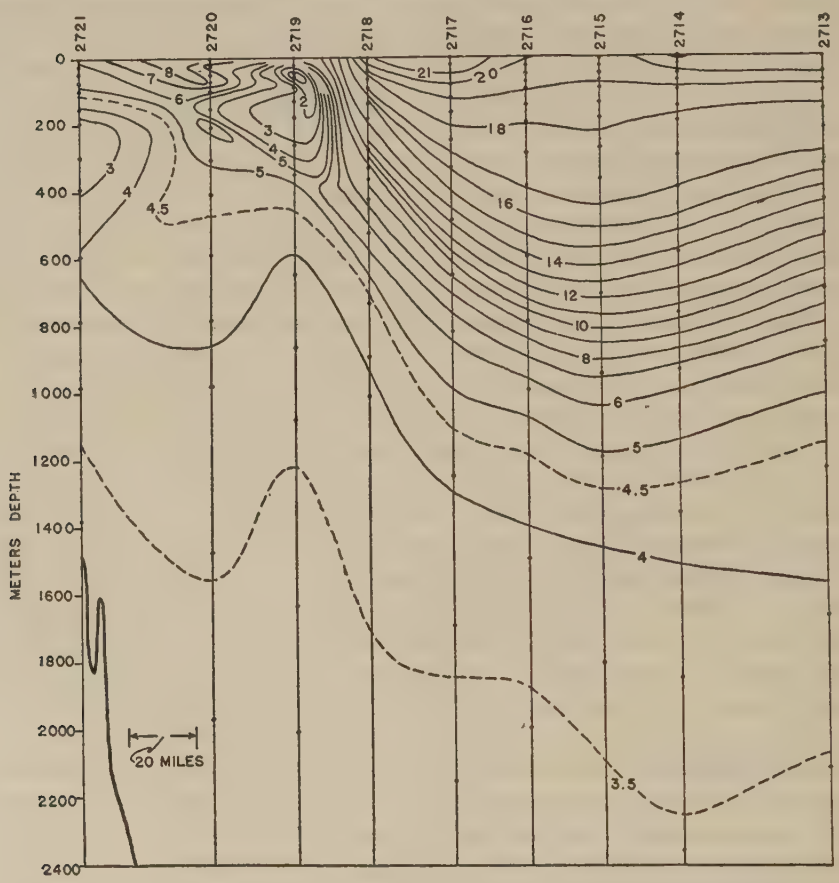

FIGURE 50.—Temperature profile across Gulf Stream near fiftieth meridian, June 3–4, 1938.

south of the Grand Banks, and occupied during the third current survey, June 3–4, 1938, has been examined. Figure 50 shows the temperature distribution along this section. It was assumed that the upper 100 meters was uniformly mixed at each of the stations and the resulting mean values of temperatures and salinities were used to determine anomalies of dynamic height for the upper 100 meters. At each station the resulting figure was compared with the anomaly of dynamic height computed from the measured values of temperature and salinity. The changes in dynamic height of the surface which would occur

under such conditions are plotted in figure 51. From this it will be seen that the surface velocity would be increased by the resulting two to three millimeters increase in the gradient between stations 2715 and 2720. On the assumption made, a discontinuity surface would exist at a depth of 100 meters.

If the energy involved in such a change is to be considered, it is not sufficient to deal with surface velocities alone, but volumes of flow must be examined. Just as in the upper part of this 100-meter layer the velocities were increased, so in the lower part the velocities were decreased even more. In the numerical determination of the volume of flow between stations 2715 and 2720 the effect of such mixing would be to decrease the volume of flow by about 0.07 million cubic meters per second. Thus it is seen that the result of such hypothetical uniform adiabatic mixing caused by the passage of a storm over such an area is a decrease in energy of the current system and an increase in the surface velocity. It is suggested that although the magnitude of the resulting effect seems small in the instance here examined, it may be of considerable importance taken over protracted periods and in other localities. It may be well to point out that the foregoing considers only the effects of internal density changes and not the effect of tangential stress produced by wind at the air-water boundary.

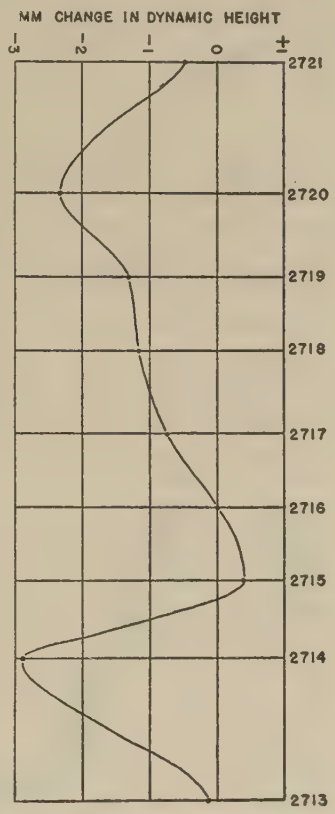

FIGURE 51.—Change in dynamic height of sea surface which would result if upper 100 meters were uniformly mixed. Section across Gulf Stream near fiftieth meridian, June 3 and 4, 1938.

The route synopsis and general description of the work undertaken on the 1938 post-season cruise has been given on page 115. Figure 52 shows the disposition of the oceanographic stations and gives the dynamic topography of the surface. A reference surface of 2,000 decibars has been used since the extensive survey of 1935 indicated that, at least in the southern part of the Labrador Sea, the depth of the most nearly motionless surface was about 2,000 meters. The effect of the shoal off Hamilton Inlet is shown on the Labrador side and the West Greenland Current is evident rounding Cape Farewell. The branch of this current which crosses to the American side south of Davis Strait is to be seen intersecting the longitudinal section.

Both the northern end of this section and the Davis Strait section show that a part of the Baffin Land Current crossing Davis Strait Ridge extended more than half way across the strait.

FIGURE 52.—Dynamic topography of surface relative to 2,000 decibars. Post-season cruise, July 24–August 2, 1938.

The volume of flow of the various currents crossed has been computed and the results are given below in tabular form in comparison with the average of prior investigations given in detail in Bulletin No. 19, part 2 of this series. The volume of flow is given in million

cubic meters per second, heat transfer in million cubic meter degrees Centigrade per second, and mean temperature in degrees Centigrade.

TABLE 2

	Volume		Mean temperature		Heat transport	
	1938	Average	1938	Average	1938	Average
Labrador Current (South Wolf Island)	4.36	4.64	2.95	3.02	12.9	14.0
West Greenland Current (Cape Farewell)	5.43	5.2	4.69	4.74	25.5	24.6
West Greenland Current (Westward Branch)	5.51	----------	3.92	----------	21.6	----------
West Greenland Current (crossing ridge)	0.12	1.13	2.79	1.2	0.3	1.4

From the above table it will be noted that both the Labrador and West Greenland Currents, crossed by the section from South Wolf Island, Labrador, to Cape Farewell, Greenland, were flowing with about average volume, had about average temperature, and were consequently transferring about the average amount of heat past the section. The conformity of the Labrador Current is not remarkable. However, in view of other evidence from the Greenland coast that 1938 was abnormally cold [2] the apparent normality of the West Greenland Current off Cape Farewell merits closer scrutiny. It must be remembered that the West Greenland Current comes from the confluence near Cape Farewell of the cold East Greenland Current and the warm Irminger Current. It is quite possible that a change in the ratio of the volumes of these two components, compensated for by a change in the mean temperature of either or both might result in an unchanged volume of flow of the West Greenland Current having a normal mean temperature. Such a situation would be characterized by the existence of greater than normal contrasts between the cold, less saline inshore portion and the warm saltier offshore portion. No doubt these conditions prevailed during 1938. During the occupation of this section the highest temperature observed in the warm water core was 6.98° C. and the lowest observed in the inshore component was −1.45° C.

The comparison of the mean temperature of 4.69° with the average of other occupations of this section is misleading. On record are eight previous occupations of this section and they indicate that a considerable seasonal change occurs in the mean temperature of the West Greenland Current. These eight values of mean temperature,

[2] U. S. Hydrographic Office Weekly Bulletin, published the following on August 17, 1938: "Capt. J. Gabrielsen, of the Norwegian steamer *Borgfred* reports that after leaving Ivigtut, Greenland, July 25, 1938, on a passage toward Philadelphia, Pa., drift ice was encountered with rendered it necessary to steer due west for 30 miles before clearing. Ice conditions were found to be very severe this year and although bergs have always been seen, drift and pack ice which is usually gone by the end of June, was plentiful. Information was received from a Danish hydrographer that the water along the Greenland Coast was colder this year than had been observed during the past 14 years." See also, remarks on Ice Conditions, North Atlantic Ocean, 1938, July, August, and September in an earlier part of this Bulletin.

from the different occupations of this section, have been plotted against time of year with the result shown in figure 53. A smooth curve has been drawn through the points to indicate the average seasonal variation of the mean temperature. The value for 1938 has also been shown in the figure and is seen to be about 0.3° lower than the value indicated by the curve for the same time of year. Admittedly, the data are too scanty to draw such a curve accurately but even though these data are few, and taken from different years, it seems apparent that a decided increase in the mean temperature occurs during the summer months and that the 1938 value is lower than any normal indicated by such a curve.

The temperature distribution along the section from South Wolf Island to Cape Farewell for depths greater than 100 meters is shown

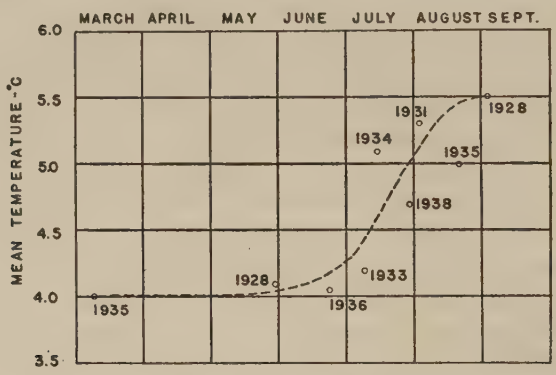

FIGURE 53.—Seasonal variation in mean temperature of the West Greenland Current at Cape Farewell from measurements made from *Marion*, 1928; *Godthaab*, 1928; *Meteor*, 1935; and *General Greene*, 1931, 1933, 1934, 1935, 1936, and 1938.

in figure 54. At the left hand side of the figure the Labrador Current is to be seen with its frigid Baffin Land Current component over the shelf and its warm West Greenland Current component over the slope. Similarly at the right hand side of the figure the warm Irminger Current component and the cold East Greenland Current component can be identified as the offshore and inshore parts of the West Greenland Current. In the central part of the basin the large body of characteristically uniform intermediate water extends to a depth of about 2,000 meters. Below this depth the deep water grades more steeply to the cold bottom water.

The temperature maximum of the intermediate water with values between 3.2 and 3.3° C. is pointed out and will be discussed later in connection with the temperature profile along the longitudinal section.

The dynamic topographic map of the surface (fig. 52) indicates that station 2822, located at 57°25′ N., 48°47′ W., is nearest the midpoint of the quiet water between the Labrador Current off South Wolf

Island and the West Greenland Current off Cape Farewell. This station was therefore selected as the southern end of the longitudinal section extending northward to station 2838, located on Davis Strait Ridge at 65°48′ N., 57°30′ W. It will be observed from table 2 that

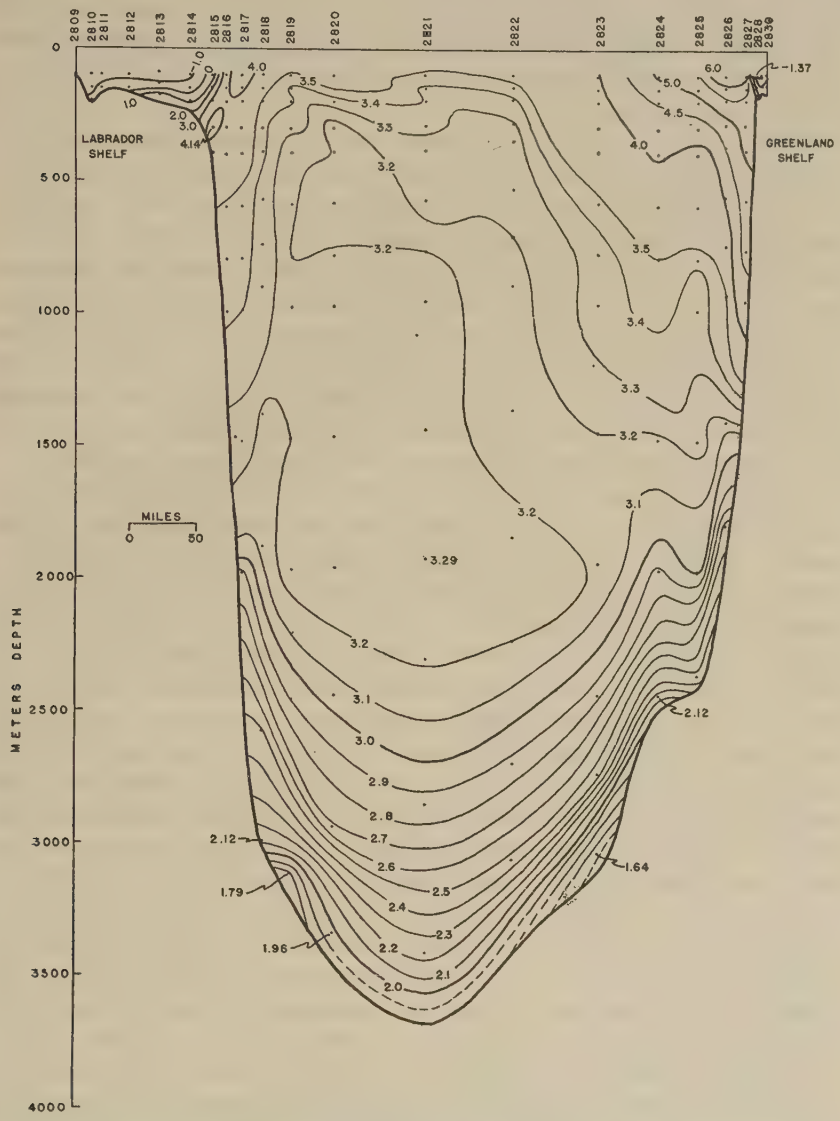

FIGURE 54.—Temperature profile, South Wolf Island, Labrador, to Cape Farewell, Greenland, July 24 to 28, 1938.

the westward transport of water across the northern end of this section is practically the same as the volume of flow of the West Greenland Current past Cape Farewell, and that both are larger than the Labrador Current off South Wolf Island, although the westward-

flowing branch of the West Greenland Current is augmented by the Baffin Land Current flowing southward across the western side of Davis Strait Ridge. This is a verification of the scheme of circulation in the Labrador Basin proposed by Smith, Soule, and Mosby in Bulletin No. 19, part 2, of this series and indicates that water from the upper faster-moving currents is contributed to the deep water circulation, through mixing, cabbeling, and sinking along the boundaries of the parent currents.

With such an hypothesis in mind the explanation is at hand for the lower mean temperature of the westward-flowing current intersecting the longitudinal section compared with the mean temperature of the West Greenland Current at Cape Farewell. Namely, part of the water passing Cape Farewell sinks below the reference level of the velocity profiles (1,500 decibars) and is replaced by colder water of the Baffin Land Current as indicated by the surface map (fig. 52). Further contributions to the deep water are made between Davis Strait and South Wolf Island, not completely compensated for by the addition of that part of the cold Baffin Land Current which enters the Labrador Sea west of the longitudinal section.

Only a very small amount of the West Greenland Current continued north across the Davis Strait section into Baffin Bay. This small volume of flow of 0.12 million cubic meters per second had a mean temperature of 2.79° C. compared with a previously measured value of 1.2° C. It is probable that just north of Davis Strait Ridge part of the Baffin Land Current crosses to the Greenland side and joins the West Greenland Current on its way northward. If so it is also probable that the earlier measurements included a part of this cold current, increasing the volume figure and decreasing the mean temperature figure, in which case the 1938 values would be more nearly representative of the West Greenland Current which actually crosses the ridge. That portion of the Baffin Land Current crossing the Davis Strait section (east of station 2838) was found to have a volume of flow of 0.53 million cubic meters per second and a mean temperature of 1.72° C. As this represents by no means all of the Baffin Land Current entering the Labrador Sea it is without significance as far as that current is concerned. However, since this water also crossed the longitudinal section at the northern end it provides a means of correcting the apparent volume of flow of the west-flowing branch of the West Greenland Current. Applying this correction leaves as the true West Greenland Current a volume of 4.98 and a heat transfer of 20.6, which adjusted figures produce a revised value of the mean temperature of this branch of 4.13° C. Even these adjusted values and the uncertainty as to normal conditions in this region leave as unescapable the conclusion that an abnormally large proportion of the West Greenland Current branched

westward to the American side south of Davis Strait Ridge during the summer of 1938.

In Bulletin No. 19, part 2 of this series, a composite longitudinal profile of dissolved oxygen is shown, based on measurements made on the *Godthaab* in 1928 and on the *General Greene* in 1935. As the section was made up of stations not ideally situated to portray the longitudinal distribution and as there seemed to be a difference in

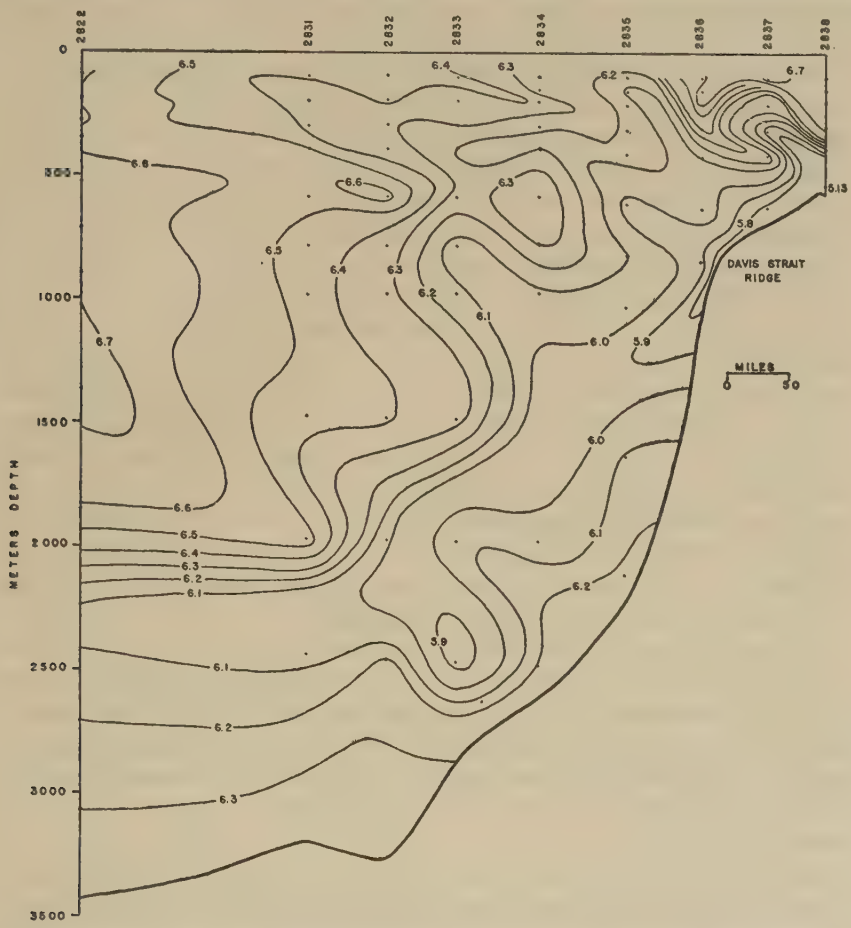

FIGURE 55.—Oxygen profile, longitudinal section Labrador Basin to Davis Strait Ridge, July 27–August 1, 1938.

absolute values between the *Godthaab's* 1928 and the *General Greene's* 1935 values, oxygen determinations were made at all stations along the 1938 longitudinal section from depths of 100 meters down to the deep water with the result shown in figure 55. As figure 55 cuts through the middle of the area proposed by Smith, Soule, and Mosby as that in which bottom water is formed in wintertime by convectional mixing from surface to bottom, it is of particular interest.

One of the difficulties with this explanation of the formation of bottom water has been that the bottom water in summer had amounts of dissolved oxygen considerably below the values given by Fox for saturation at the low wintertime temperature required for convectional vertical mixing. Figure 55 indicates a solution to this difficulty. Smith, Soule, and Mosby have shown that on the basis of summertime measurements of temperature and salinity the maximum temperature at which convectional mixing to bottom could occur, in the absence of horizontal movements, was about 2.0° C. If 90 percent of the Fox "saturation" figure is taken as a fair value, we could expect to get about 6.9 ml. per liter of dissolved oxygen into the water during the convection process. The Baffin Bay water just north of Davis Strait Ridge is known from the *Godthaab's* measurements to be very low in oxygen. These measurements, verified by the deepest observation of the *General Greene* at station 2838, show that the oxygen content of water crossing the ridge into the Labrador Basin would be about 5.0 ml. per liter.

Figure 55 shows clearly an oxygen minimum extending from Davis Strait Ridge down the Labrador Basin slope to the boundary between the intermediate water and deep water (between about 2,000 and 2,500 meters) and indicates the movement of Baffin Bay water into the Labrador Basin. If such water is mixed with the Labrador Basin water with an oxygen content of 6.9 ml. per liter in a proportion as much as one-quarter Baffin Bay water to three-quarters Labrador Basin water we come out with an oxygen content of the mixture of 6.4 ml. per liter, which is about the value shown in figure 55 for the bottom water in the Labrador Basin.

Presumably such a contribution of Baffin Bay water is not confined to the brief season during which convectional mixing is possible but continues after the vertical convection stops, thus establishing the oxygen minimum shown in figure 55. It should be emphasized in considering this Baffin Bay contribution that south is not a major component of its motion but the result is attained through lateral mixing.

Smith, Soule, and Mosby have also shown that to qualify as a constituent of the bottom water, the vertically mixed water should have a salinity between about 34.81 and 34.91 ‰. It has been shown that the mean salinity of the water column in this region is about 34.88 ‰ in summer. Station 2838 shows that the water near bottom on the ridge has a summertime salinity of about 34.60 ‰. A mixture of waters of such salinities in the above-mentioned proportion would result in a salinity of the mixture of about 34.80 ‰ which closely approaches the limit of 34.81 ‰.

It must be remembered in connection with the above discussion that as the contribution from Baffin Bay proceeds from Davis Strait

ridge down the slope to the deep water of the Labrador Basin its sinking is accompanied by the process of cabbeling and mixing with the border of the westward-flowing branch of the comparatively warm, salty, West Greenland Current; just as such cabbeling, mixing and sinking takes place on the Labrador Sea side (southern) boundary of this current. Both factors combine to produce a temperature max-

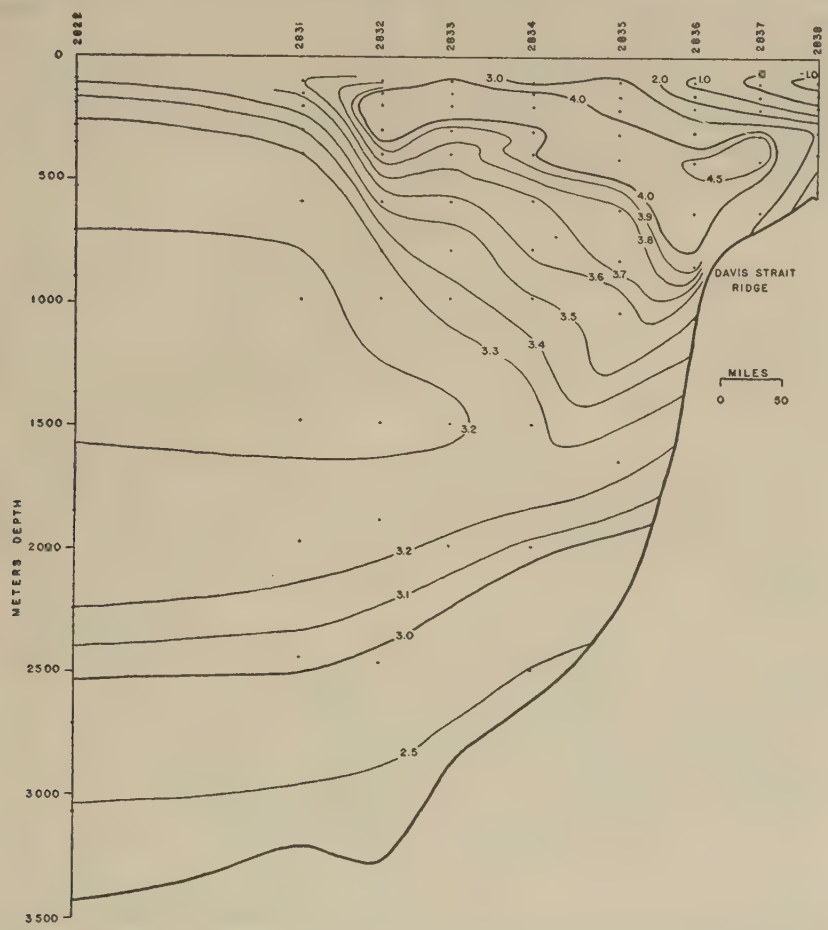

FIGURE 56.—Temperature profile, longitudinal section Labrador Basin to Davis Strait Ridge, July 27–August 1, 1938.

imum layer near the boundary between the intermediate water and deep water as shown in figure 56, the temperature profile of the longitudinal section. It has been mentioned before and is here emphasized again, that this cabbeling, mixing, and sinking takes place all along the boundaries of the more rapidly moving currents of the circulatory system of the Labrador Sea and is not restricted to any single locality. Thus the temperature maximum shown in figure 56 should

not be considered to be solely the result of contributions from the north but from the Labrador and Greenland margins of the basin as well. Attention is again directed to figure 54 from which it will be seen that the thickness of this temperature maximum layer is much greater nearer the Labrador side than it is at station 2822 (which station also forms the end of the longitudinal section). As it has been shown also that the mixed water formed by these processes slowly moves cyclonically with the parent currents it is understandable that the cross-sectional area of this water of the temperature maximum is greater on the Labrador side than on the Greenland side. Similarly the intermediate temperature minimum may be looked upon as indicating water of least activity.

SUMMARY

1. The four current surveys of the Ice Patrol area in the vicinity of the Grand Banks, made during the 1938 season, have been described.

2. Computations have been made and the results presented to show the seasonal variation of the Labrador Current during 1938 as compared with similar variations found during the previous four ice seasons.

3. The boundary between Atlantic Current water and Labrador Current water, based on the horizontal projection of the course of the zero salinity anomaly at the intermediate salinity anomaly maximum, was investigated, but found to be outside the limits of the 1938 surveys.

4. A section across the Gulf Stream near the fiftieth meridian, occupied during June 1938, has been discussed with respect to volume of flow, heat transport, and mean temperature.

5. Quantitative consideration has been given an actual section with regard to the magnitude of the effect of a storm-produced, hypothetically uniform, vertical mixing of the upper 100 meters.

6. The circulatory system of the upper layers of the Labrador Sea has been discussed from the standpoint of volumes of flow, mean temperatures and heat transport values derived from measurements made during 1938 on sections across the Labrador Current off South Wolf Island, across the West Greenland Current off Cape Farewell, across the west-flowing branch of the West Greenland Current south of Davis Strait Ridge, and across a part of the Baffin Land Current and the West Greenland Current at Davis Strait.

7. New data on the oxygen distribution along a longitudinal section through the northern part of the Labrador Sea are presented and discussed with relation to the source of the bottom water of the Labrador Sea.

In the following table are given the data collected during the 1938 season and post-season cruises. The individual station headings give

the station number, date, geographical position, depth of water, and dynamic height of the sea surface above the reference surface used in the construction of the dynamic topographic charts shown in figures 45, 46, 47, 48, and 52. For stations 2541 to 2808, inclusive, the sea surface is referred to the 1,000-decibar surface and the depth of water is the uncorrected fathometer sounding based on a sounding velocity of 1,447 meters per second. For stations 2809 to 2847, inclusive, the sea surface is referred to the 2,000-decibar surface and the depth of water is the sonic sounding corrected for sounding velocity and draft but not for slope. Where the depth of the scaled values is enclosed in parentheses the data are based on extrapolated vertical distribution curves of temperature or salinity or both. Asterisks appearing before observed temperatures indicate that these temperatures were determined from the depth of reversal and the corrected reading of an unprotected thermometer. The symbol σ_t signifies 1,000 (density−1).

Table of oceanographic data

STATIONS OCCUPIED IN 1938

Station 2541; Mar. 31; latitude 43°34′ N., longitude 53°45′ W., depth 3,329 meters, dynamic height 970.982 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	3.03	33.52	0	3.03	33.53	26.73
25	3.01	33.52	25	3.01	33.52	26.72
50	2.95	33.53	50	2.95	33.53	26.73
75	2.60	33.80	75	2.60	33.80	26.98
100	3.60	34.05	100	3.60	34.05	27.09
150	4.80	34.54	150	4.80	34.54	27.35
201	4.02	34.56	200	4.05	34.56	27.44
301	5.05	34.88	300	5.05	34.88	27.59
372	4.03	34.82	400	4.05	34.82	27.65
560	4.21	34.93	600	4.20	34.93	27.73
749	3.96	34.93	800	3.90	34.93	27.76
942	3.85	34.92	1,000	3.80	34.93	27.77
1,334	3.54	34.93				

Station 2542; Mar. 31; latitude 43°39′ N., longitude 53°03′ W., depth 2,149 meters, dynamic height 970.998 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	1.42	33.58	0	1.42	33.58	26.89
25	1.46	33.57	25	1.46	33.57	26.88
51	1.86	33.66	50	1.80	33.65	26.93
76	3.66	34.04	75	3.65	34.04	27.08
101	3.61	34.11	100	3.60	34.10	27.13
152	3.27	34.29	150	3.30	34.28	27.30
203	1.95	34.23	200	2.00	34.23	27.37
304	3.78	34.58	300	3.75	34.57	27.48
400	2.65	34.53	400	2.65	34.53	27.56
599	2.35	34.92	600	2.35	34.65	27.68
798	3.68	34.89	800	3.65	34.89	27.75
998	3.56	34.89	1,000	3.55	34.89	27.76
1,399	3.47	34.90				

Station 2543; Apr. 1; latitude 43°43′ N., longitude 52°43′ W., depth 1,463 to 1,774 meters, dynamic height 971.029 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	2.74	33.40	0	2.74	33.40	26.65
26	2.81	33.44	25	2.85	33.44	26.67
51	7.99	34.57	50	7.90	34.55	26.95
77	8.47	34.72	75	8.45	34.71	26.99
103	8.75	34.82	100	8.75	34.81	27.02
154	8.16	34.87	150	8.20	34.87	27.16
206	7.18	34.89	200	7.25	34.88	27.30
309	2.65	34.49	300	2.70	34.50	27.53
394	3.63	34.64	400	3.65	34.65	27.56
597	3.89	34.85	600	3.90	34.85	27.70
803	3.94	34.90	800	3.95	34.90	27.73
1,006	3.69	34.90	1,000	3.70	34.90	27,76
1,412	3.37	34.89				

Station 2544; Apr. 1; latitude 43°45′ N., longitude 52°29′ W., depth 640 meters, dynamic height 971.044 meters

Observed values			Scaled values			
Depth, meters	Temperature °C.	Salinity ‰	Depth, meters	Temperature °C	Salinity ‰	σ_t
0	1.40	32.88	0	1.40	32.88	26.34
25	2.49	33.37	25	2.49	33.37	26.64
50	5.47	34.06	50	5.47	34.06	26.88
76	7.52	34.59	75	7.50	34.58	27.03
101	7.74	34.66	100	7.75	34.66	27.06
151	6.27	34.58	150	6.25	34.58	27.20
202	7.50	34.84	200	7.45	34.82	27.24
303	3.42	34.47	300	3.50	34.47	27.43
408	4.07	34.71	400	4.05	34.70	27.56
610	3.77	34.85	600	3.80	34.84	27.70

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2545; Apr. 1; latitude 43°47′ N., longitude 52°19′ W., depth 162 meters, dynamic height 971.081 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	1.41	32.62	0	1.41	32.62	26.13
28	1.39	32.65	25	1.40	32.65	26.15
56	0.54	33.40	50	0.60	33.21	26.65
83	3.57	33.92	75	2.40	33.78	26.98
111	4.89	34.17	100	4.55	34.07	27.00
167	4.63	34.21	150	4.70	34.20	27.10

Station 2546; Apr. 1; latitude 43°50′ N., longitude 51°55′ W., depth 88 meters, dynamic height 971.272 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.09	32.40	0	2.09	32.40	25.90
26	1.87	32.42	25	1.90	32.42	25.94
53	1.88	32.42	50	1.90	32.42	25.94
79	0.62	33.05	75	0.90	32.95	26.42

Station 2547; Apr. 1; latitude 43°40′ N., longitude 52°04′ W., depth 165 meters, dynamic height 971.105 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.01	32.53	0	2.01	32.53	26.02
26	1.27	32.62	25	1.30	32.62	26.15
52	1.27	32.71	50	1.25	32.70	26.20
78	0.23	33.28	75	0.25	33.26	26.71
104	0.29	33.53	100	0.25	33.50	26.91
156	3.33	33.99	150	3.00	33.95	27.07

Station 2548; Apr. 1; latitude 43°33′ N., longitude 52°09′ W., depth 631 meters, dynamic height 971.059 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	1.99	32.63	0	1.99	32.63	26.10
26	3.73	33.62	25	3.75	33.61	26.73
51	5.67	34.09	50	5.60	34.08	26.90
77	8.36	34.70	75	8.30	34.69	27.00
103	8.69	34.82	100	8.70	34.82	27.05
154	4.36	34.17	150	4.50	34.17	27.10
206	5.79	34.53	200	5.65	34.52	27.24
309	4.40	34.58	300	4.45	34.57	27.42
403	4.23	34.71	400	4.25	34.70	27.54
601	3.79	34.83	600	3.80	34.83	27.70

Station 2549; Apr. 1; latitude 43°25′ N., longitude 52°16′ W., depth 1,463 meters, dynamic height 971.061 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.43	33.67	0	3.43	33.67	26.81
25	4.58	33.93	25	4.58	33.93	26.90
50	3.84	33.85	50	3.84	33.85	26.90
75	3.34	33.83	75	3.34	33.83	26.94
100	2.64	33.93	100	2.64	33.93	27.09
150	5.42	34.41	150	5.42	34.41	27.18
201	5.16	34.44	200	5.15	34.44	27.23
301	4.00	34.43	300	4.00	34.43	27.36
399	4.63	34.72	400	4.65	34.72	27.52
602	4.42	34.89	600	4.45	34.89	27.67
803	3.87	34.89	800	3.85	34.89	27.73
1,005	3.58	34.87	1,000	3.55	34.87	27.75
1,408	3.40	34.88				

Station 2550; Apr. 1; latitude 43°03′ N., longitude 52°32′ W., depth 3,136 meters, dynamic height 971.062 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.13	33.22	0	2.13	33.22	26.57
25	3.12	33.83	25	3.12	33.83	26.96
51	3.73	33.97	50	3.75	33.96	27.01
76	5.24	34.26	75	5.20	34.26	27.09
102	4.24	34.13	100	4.30	34.14	27.09
153	5.30	34.43	150	5.25	34.42	27.21
204	3.20	34.22	200	3.40	34.23	27.26
306	1.35	34.19	300	1.35	34.19	27.39
361	*1.70	34.27	400	2.00	34.34	27.46
541	3.18	34.63	600	3.40	34.70	27.63
722	3.69	34.80	800	3.75	34.83	27.70
908	3.72	34.86	1,000	3.70	34.87	27.74
1,289	3.62	34.89				

Station 2551; Apr. 1–2; latitude 42°31′ N,, longitude 52°52′ W., depth 3,795 meters, dynamic height 971.060 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.40	33.42	0	3.40	33.42	26.61
25	3.17	33.41	25	3.17	33.41	26.63
51	8.74	34.55	50	8.60	34.49	26.80
76	10.32	35.05	75	10.35	35.05	26.95
101	9.97	35.03	100	9.95	35.03	27.01
152	9.45	35.11	150	9.50	35.11	27.14
203	7.03	34.78	200	7.20	34.79	27.24
304	5.08	34.65	300	5.10	34.65	27.41
402	4.55	34.77	400	4.55	34.76	27.56
605	4.63	34.95	600	4.65	34.95	27.70
809	4.05	34.93	800	4.05	34.93	27.75
1,010	3.96	34.93	1,000	3.95	34.93	27.76
1,413	3.63	34.92				

Station 2552; Apr. 2; latitude 41°57′ N., longitude 52°04′ W., depth 3,731 meters, dynamic height 971.147 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	11.13	35.23	0	11.13	35.23	26.95
25	11.15	35.22	25	11.15	35.23	26.95
50	11.15	35.23	50	11.15	35.23	26.95
74	11.15	35.23	75	11.15	35.23	26.95
99	11.16	35.24	100	11.15	35.24	26.95
149	11.46	35.33	150	11.45	35.33	26.97
199	11.47	35.32	200	11.45	35.32	26.97
298	9.50	35.19	300	9.45	35.18	27.21
406	7.83	35.07	400	7.95	35.07	27.36
607	5.00	34.94	600	5.05	34.94	27.64
807	4.61	35.00	800	4.60	35.00	27.74
1,009	4.13	34.95	1,000	4.15	34.96	27.76
1,412	3.70	34.93				

Station 2553; Apr. 2; latitude 42°22′ N., longitude 51°35′ W., depth 2,698 meters, dynamic height 970.976 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	5.24	33.97	0	5.24	33.97	26.85
25	6.15	34.21	25	6.15	34.21	26.93
49	6.01	34.19	50	6.00	34.19	26.93
74	5.92	34.20	75	5.95	34.20	26.95
98	4.58	34.17	100	4.30	34.16	27.11
147	1.37	34.01	150	1.35	34.01	27.25
196	1.70	34.20	200	1.80	34.22	27.38
294	4.60	34.80	300	4.60	34.81	27.59
354	4.38	34.86	400	4.25	34.87	27.67
534	3.95	34.89	600	3.95	34.89	27.72
717	3.89	34.91	800	3.75	34.91	27.76
906	3.58	34.90	1,000	3.50	34.89	27.77
1,298	3.34	34.88				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2554; Apr. 2; latitude 42°45′ N., longitude 51°07′ W., depth 1,463 meters, dynamic height 971.061 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.62	33.35	0	0.62	33.35	26.76
23	1.11	33.48	25	1.15	33.49	26.84
47	1.62	33.58	50	1.75	33.60	26.89
70	2.57	33.71	75	2.65	33.72	26.91
93	2.75	33.76	100	2.70	33.78	26.95
140	2.60	33.95	150	2.80	34.02	27.14
187	4.08	34.29	200	3.85	34.30	27.27
280	3.03	34.33	300	3.15	34.39	27.40
323	3.39	34.49	400	3.40	34.61	27.56
494	3.38	34.69	600	3.55	34.76	27.66
670	3.66	34.79	800	3.70	34.82	27.69
855	3.69	34.83	1,000	3.60	34.84	27.72
1,245	3.42	34.87				

Station 2555; Apr. 2; latitude 42°54′ N., longitude 50°57′ W., depth 631 meters, dynamic height 971.121 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.42	33.11	0	−0.42	33.11	26.62
25	−0.64	33.12	25	−0.64	33.12	26.64
49	−0.73	33.14	50	−0.75	33.14	26.65
74	−1.00	33.23	75	−1.00	33.23	26.74
98	−0.81	33.30	100	−0.75	33.31	26.79
147	0.30	33.46	150	0.30	33.47	26.87
196	0.11	33.61	200	0.15	33.62	27.00
294	2.81	34.22	300	2.80	34.24	27.32
383	2.75	34.45	400	2.80	34.47	27.49
583	3.51	34.75	600	3.50	34.76	27.67

Station 2556; Apr. 2; latitude 43°05′ N., longitude 50°43′ W., depth 88 meters, dynamic height 971.083 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.69	33.27	0	0.69	33.27	26.69
27	0.47	33.28	25	0.50	33.28	26.70
54	0.38	33.28	50	0.40	33.28	26.71
81	−0.06	33.44	75	0.00	33.38	26.82

Station 2557; Apr. 3; latitude 43°24′ N., longitude 50°18′ W., depth 55 meters, dynamic height 971.093 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.65	33.02	0	0.65	33.02	26.49
28	0.52	33.08	25	0.55	33.08	26.54
50	0.57	33.16	50	0.55	33.16	26.61

Station 2558; Apr. 3; latitude 42°54′ N., longitude 50°21′ W., depth 88 meters, dynamic height 971.076 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.21	33.33	0	0.21	33.33	26.77
27	1.18	33.49	25	1.10	33.48	26.83
55	2.76	33.70	50	2.50	33.67	26.88
82	4.05	33.92	75	3.70	33.85	26.92

Station 2559; Apr. 3; latitude 42°50′ N., longitude 50°21′ W., depth 167 to 157 meters, dynamic height 971.080 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.05	33.17	0	0.05	33.17	26.65
25	−0.45	33.28	25	−0.45	33.28	26.75
50	−0.10	33.35	50	−0.10	33.35	26.79
75	1.73	33.63	75	1.73	33.63	26.91
100	4.33	34.08	100	4.33	34.08	27.03
150	5.04	34.18	150	5.04	34.18	27.04

Station 2560; Apr. 3; latitude 42°40′ N., longitude 50°22′ W., depth 677 to 640 meters, dynamic height 971.032 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.53	33.21	0	−0.53	33.21	26.70
23	−0.67	33.24	25	−0.65	33.25	26.74
46	−0.83	33.39	50	−0.80	33.40	26.87
69	−0.77	33.42	75	−0.70	33.43	26.89
92	−0.53	33.48	100	−0.30	33.51	26.94
138	2.31	33.86	150	4.10	34.19	27.15
184	7.04	34.77	200	6.55	34.74	27.29
276	4.03	34.61	300	3.50	34.60	27.54
343	3.00	34.59	400	3.20	34.62	27.58
528	3.54	34.75	(600)	3.60	34.80	27.69

Station 2561; Apr. 3; latitude 42°33′ N., longitude 50°22′ W., depth 1,472 to 1,317 meters, dynamic height 971.000 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	5.49	34.12	0	5.49	34.12	26.93
22	5.52	34.15	25	5.65	34.16	26.95
43	6.33	34.31	50	6.20	34.28	26.97
65	5.18	34.15	75	4.95	34.11	27.00
87	4.68	34.07	100	4.00	33.99	27.00
130	2.46	33.87	150	2.45	34.00	27.15
173	2.46	34.18	200	2.45	34.27	27.36
260	2.54	34.43	300	3.00	34.57	27.56
296	2.98	34.56	400	3.70	34.78	27.66
445	3.84	34.82	600	3.75	34.85	27.71
594	3.74	34.85	800	3.80	34.87	27.72
755	3.82	34.87	1,000	3.60	34.87	27.74
1,093	3.51	34.87				

Station 2562; Apr. 3; latitude 42°18′ N., longitude 50°22′ W., depth 2,552 meters, dynamic height 970.958 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.96	34.29	0	6.96	34.29	26.88
25	6.87	34.32	25	6.87	34.32	26.91
49	7.01	34.39	50	7.00	34.39	26.96
74	6.95	34.39	75	6.95	34.39	26.96
98	4.65	34.25	100	4.65	34.27	27.15
147	5.59	34.73	150	5.60	34.74	27.41
195	5.52	34.83	200	5.50	34.83	27.50
293	4.40	34.82	300	4.40	34.82	27.61
275	4.73	34.84	400	4.50	34.93	27.69
428	4.51	34.94	600	4.05	34.90	27.72
590	4.07	34.90	800	3.90	34.92	27.75
772	3.94	34.92	1,000	3.65	34.91	27.77
1,177	3.46	34.90				

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Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2563; Apr. 3; latitude 41°59′ N., longitude 50°19′ W., depth 3,091 meters, dynamic height 970.943 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.19	33.63	0	3.19	33.63	26.79
28	3.17	33.64	25	3.20	33.64	26.80
54	2.96	33.64	50	3.00	33.64	26.82
82	4.60	34.46	75	4.10	34.34	27.27
109	4.12	34.47	100	4.35	34.47	27.34
163	2.58	34.38	150	2.85	34.39	27.43
217	4.32	34.71	200	3.85	34.67	27.55
326	4.54	34.87	300	4.55	34.84	27.62
370	4.42	34.90	400	4.40	34.91	27.69
567	4.12	34.92	600	4.05	34.92	27.73
773	3.85	34.90	800	3.80	34.90	27.75
989	3.61	34.90	1,000	3.60	34.89	27.76
1,450	3.38	34.87				

Station 2564; Apr. 3; latitude 41°29′ N., longitude 50°16′ W., depth 3,795 meters, dynamic height 970.966 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	4.14	33.65	0	4.14	33.65	26.72
31	3.40	33.65	25	3.55	33.65	26.78
61	3.01	33.67	50	3.20	33.66	26.82
92	2.40	33.97	75	2.80	33.78	26.95
122	3.07	34.33	100	2.50	34.06	27.20
183	3.59	34.58	150	3.30	34.47	27.45
245	4.02	34.71	200	3.70	34.62	27.53
367	4.41	34.88	300	4.30	34.80	27.62
473	4.16	34.89	400	4.35	34.89	27.68
711	3.78	34.87	600	3.95	34.88	27.71
948	3.52	34.86	800	3.65	34.86	27.73
1,187	3.40	34.86	1,000	3.50	34.86	27.75
1,670	3.35	34.87				

Station 2565; Apr. 4; latitude 40°57′ N., longitude 50°12′ W., depth 3,658 meters, dynamic height 971.060 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	4.79	33.79	0	4.79	33.79	26.76
25	4.88	33.93	25	4.88	33.93	26.86
50	7.91	34.55	50	7.91	34.55	26.95
75	8.93	34.75	75	8.93	34.75	26.95
100	9.21	34.82	100	9.21	34.82	26.96
150	5.39	34.34	150	5.39	34.34	27.11
199	8.29	34.99	200	8.25	34.99	27.25
299	4.61	34.55	300	4.65	34.55	27.38
364	6.17	34.94	400	5.80	34.94	27.55
548	4.52	34.91	600	4.25	34.89	27.69
734	3.84	34.87	800	3.90	34.88	27.72
924	4.06	34.93	1,000	3.95	34.93	27.75
1,311	3.50	34.88				

Station 2566; Apr. 4; latitude 41°39′ N., longitude 49°31′ W., depth 3,155 meters, dynamic height 971.104 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	12.86	35.56	0	12.86	35.56	26.88
28	12.78	35.58	25	12.80	35.58	26.90
55	12.85	35.56	50	12.85	35.57	26.89
83	12.71	35.54	75	12.75	35.55	26.89
110	12.70	35.55	100	12.70	35.55	26.90
165	11.02	35.24	150	11.50	35.31	26.95
220	9.57	35.11	200	10.05	35.15	27.08
330	7.44	35.00	300	8.00	35.03	27.31
440	5.48	34.91	400	6.15	34.93	27.49
658	4.58	34.96	600	4.75	34.95	27.68
877	4.15	34.94	800	4.25	34.95	27.74
1,097	3.84	34.93	1,000	3.95	34.93	27.75
1,539	3.45	34.90				

Station 2567; Apr. 4: latitude 41°59′ N., longitude 48°35′ W., depth 3,246 meters, dynamic height 970.969 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	4.66	33.78	0	4.66	33.78	26.77
25	4.75	33.83	25	4.75	33.83	26.79
51	4.24	33.92	50	4.25	33.91	26.91
76	7.98	34.83	75	8.00	34.83	27.16
102	7.77	34.86	100	7.80	34.86	27.21
153	5.94	34.68	150	6.05	34.69	27.32
204	4.64	34.62	200	4.65	34.62	27.44
306	4.58	34.80	300	4.60	34.79	27.57
405	4.64	34.93	400	4.65	34.93	27.68
606	4.23	34.94	600	4.25	34.94	27.74
806	3.88	34.92	800	3.90	34.92	27.76
1,007	3.59	34.89	1,000	3.60	34.89	27.76
1,408	3.42	34.89				

Station 2568; Apr. 4; latitude 42°42′ N., longitude 49°11′ W., depth 2,122 meters, dynamic height 970.938 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	5.06	34.02	0	5.06	34.02	26.92
25	5.10	34.04	25	5.10	34.04	26.92
51	4.93	34.06	50	5.00	34.06	26.95
76	4.05	34.06	75	4.10	34.06	27.05
102	3.33	34.16	100	3.35	34.14	27.18
153	4.33	34.55	150	4.30	34.52	27.40
203	4.31	34.76	200	4.30	34.75	27.58
305	4.22	34.86	300	4.25	34.86	27.67
400	4.07	34.88	400	4.05	34.88	27.70
600	3.80	34.88	600	3.80	34.88	27.73
800	3.50	34.88	800	3.50	34.88	27.76
1,000	3.51	34.88	1,000	3.50	34.88	27.76
1,400	3.30	34.86				

Station 2569; Apr. 5; latitude 43°20′ N., longitude 49°04′ W., depth 1,463 meters, dynamic height 971.000 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.41	33.29	0	−0.41	33.29	26.76
25	−0.29	33.47	25	−0.29	33.47	26.91
50	2.10	33.79	50	2.10	33.79	27.01
74	4.05	34.10	75	4.05	34.10	27.09
99	0.20	33.85	100	0.20	33.85	27 19
149	1.44	34.12	150	1.45	34.12	27.33
199	1.87	34.27	200	1.90	34.27	27.42
298	2.57	34.51	300	2.50	34.49	27.54
325	2.59	34.52	400	2.95	34.61	27.60
489	3.22	34.67	600	3.60	34.75	27.65
654	3.72	34.79	800	3.75	34.84	27.71
832	3.76	34.84	1,000	3.60	34.86	27.74
1,206	3.46	34.87				

Station 2570; Apr. 5; latitude 43°03′ N., longitude 48°27′ W., depth 2,880 meters, dynamic height 970.997 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.55	34.50	0	7.55	34.50	26.97
25	8.04	34.62	25	8.04	34.62	26.99
51	------	34.91	50	9.35	34.91	27.01
76	8.76	34.81	75	8.80	34.81	27.02
101	6.92	34.54	100	7.00	34.54	27.08
152	6.16	34.54	150	6.15	34.54	27.19
203	7.33	34.90	200	7.30	34.88	27.30
304	5.10	34.82	300	5.15	34.82	27.54
402	4.81	34.90	400	4.80	34.90	27.64
601	4.19	34.92	600	4.20	34.92	27.73
800	3.96	34.92	800	3.95	34.92	27.75
1,000	3.50	34.89	1,000	3.50	34.88	27.76
1,400	3.30	34.87				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2571; Apr. 5; latitude 42°33′ N., longitude 47°36′ W., depth 3,357 meters, dynamic height 971.205 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.99	35.78	0	13.99	35.78	26.80
25	13.97	35.78	25	13.97	35.78	26.81
50	13.96	35.78	50	13.96	35.78	26.81
75	13.96	35.78	75	13.96	35.78	26.81
100	13.96	35.78	100	13.96	35.78	26.81
150	13.98	35.78	150	13.95	35.78	26.81
200	13.87	35.76	200	13.87	35.76	26.82
300	10.30	35.19	300	10.30	35.19	27.06
374	8.12	35.01	400	7.60	35.00	27.35
561	5.41	-------	600	5.20	34.95	27.63
748	4.53	34.94	800	4.35	34.93	27.71
941	3.92	34.90	1,000	3.85	34.90	27.74
1,333	3.52	34.88				

Station 2572; Apr. 5; latitude 42°10′ N., longitude 46°52′ W., depth 4,253 meters, dynamic height 971.278 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	15.95	36.15	0	15.95	36.15	26.65
24	15.77	36.14	25	15.75	36.14	26.70
48	15.90	36.14	50	15.85	36.14	26.68
71	15.29	36.00	75	15.25	35.98	26.68
95	14.72	35.88	100	14.65	35.86	26.73
143	13.80	35.70	150	13.70	35.69	26.80
191	13.11	35.60	200	12.95	35.57	26.86
286	11.33	35.35	300	11.05	35.32	27.03
408	9.02	35.14	400	9.15	35.15	27.23
611	6.00	34.94	600	6.15	34.94	27.50
812	4.79	34.94	800	4.85	34.94	27.66
1,013	4.24	34.94	1,000	4.25	34.94	27.73
1,414	3.80	34.93				

Station 2573; Apr. 6; latitude 41°39′ N., longitude 45°52′ W., depth 4,436 meters, dynamic height 971.430 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	16.35	36.20	0	16.35	36.20	26.61
33	16.36	36.20	25	16.35	36.20	26.61
66	16.35	36.20	50	16.35	36.20	26.61
99	16.33	36.20	75	16.35	36.20	26.61
133	15.62	36.02	100	16.35	36.20	26.61
199	15.45	36.02	150	15.55	36.02	26.65
265	14.21	35.78	200	15.45	36.02	26.67
398	11.20	35.26	300	13.45	35.64	26.81
306	*13.76	35.62	400	11.15	35.26	26.97
466	10.32	35.24	600	7.90	34.99	27.30
630	7.39	34.95	800	5.30	34.90	27.58
777	5.44	34.90	1,000	4.60	34.96	27.71
1,059	4.50	34.96				

Station 2574; Apr. 6; latitude 42°51′ N., longitude 46°04′ W., depth 4,298 meters, dynamic height 971.428 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	15.83	36.13	0	15.83	36.13	26.67
27	15.79	36.12	25	15.80	36.12	26.67
54	15.75	36.12	50	15.75	36.12	26.68
81	15.72	36.11	75	15.75	36.11	26.67
109	15.67	36.09	100	15.70	36.10	26.68
163	15.64	36.10	150	15.65	36.10	26.70
217	15.59	36.10	200	15.65	36.10	26.70
325	*13.56	35.64	300	14.05	35.74	26.76
476	10.79	35.32	400	12.15	35.46	26.94
712	6.01	34.91	600	8.20	35.08	27.32
1,039	4.51	34.95	100	5.40	34.92	27.59
1,181	4.23	34.94	1,000	4.60	34.94	27.69
1,665	3.67	34.91				

Station 2575; Apr. 6; latitude 43°20′ N., longitude 46°00′ W., depth 4,436 meters, dynamic height 971.332 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	14.89	35.92	0	14.89	35.92	26.72
34	14.57	35.87	25	14.60	35.88	26.75
67	14.61	35.89	50	14.60	35.88	26.75
101	14.57	35.88	75	14.60	35.89	26.76
135	14.56	35.87	100	14.60	35.88	26.75
201	13.69	35.70	150	14.45	35.84	26.76
268	12.87	35.55	200	13.70	35.70	26.81
403	10.95	35.35	300	12.40	35.50	26.92
497	7.77	34.89	400	11.00	35.36	27.08
743	5.55	34.97	600	6.60	34.94	27.44
985	4.40	34.93	800	5.20	34.96	27.64
1,231	4.14	34.95	1,000	4.40	34.93	27.70
1,725	3.59	34.905				

Station 2576; Apr. 6; latitude 43°38′ N., longitude 46°50′ W., depth 4,152 meters, dynamic height 971.151 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.21	35.62	0	13.21	35.62	26.85
25	13.11	35.61	25	13.11	35.61	26.86
51	13.10	35.61	50	13.10	35.61	26.86
76	13.10	35.61	75	13.10	35.61	26.86
102	13.09	35.61	100	13.10	35.61	26.86
153	11.58	35.31	150	11.70	35.33	26.92
204	9.83	35.02	200	10.00	35.04	27.00
306	6.99	34.70	300	7.10	34.70	27.19
380	5.98	34.74	400	5.80	34.75	27.40
573	4.71	34.86	600	4.70	34.88	27.63
767	4.42	34.94	800	4.35	34.94	27.72
960	3.95	34.92	1,000	3.85	34.92	27.76
1,345	3.56	34.89				

Station 2577; Apr. 6–7; latitude 43°56′ N., longitude 47°41′ W., depth 3,704 meters, dynamic height 971.060 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	12.66	35.55	0	12.66	35.55	26.90
22	12.68	35.55	25	12.65	35.55	26.90
44	12.64	35.545	50	12.65	35.55	26.90
67	12.63	35.54	75	12.60	35.53	26.90
89	12.45	35.50	100	11.35	35.37	27.02
133	8.88	34.84	150	8.30	34.74	27.04
177	7.63	34.70	200	7.35	34.73	27.17
266	6.75	34.84	300	6.25	34.85	27.42
318	6.03	34.86	400	5.35	34.89	27.56
481	4.83	34.90	600	4.25	34.90	27.70
648	4.12	34.90	800	4.10	34.93	27.74
824	4.12	34.94	1,000	3.85	34.90	27.74
1,194	3.52	34.885				

Station 2578; Apr. 7; latitude 44°09′ N., longitude 48°18′ W., depth 3,146 meters, dynamic height 970.952 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.81	34.57	0	7.81	34.57	26.99
22	7.91	34.57	25	7.95	34.57	26.97
44	8.21	34.63	50	8.25	34.64	26.98
67	8.15	34.65	75	7.50	34.63	27.07
89	6.52	34.46	100	5.65	34.37	27.12
133	3.47	34.27	150	3.80	34.40	27.35
177	4.56	34.59	200	4.50	34.67	27.49
266	4.31	34.79	300	4.30	34.81	27.63
261	4.33	34.76	400	4.15	34.88	27.69
409	4.14	34.88	600	3.90	34.90	27.74
570	3.91	34.90	800	3.65	34.89	27.75
731	3.70	34.89	1,000	3.45	34.87	27.76
1,077	3.36	34.865				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2579; Apr. 7; latitude 44°21′ N., longitude 48°50′ W., depth 1,463 meters, dynamic height 971.004 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−1.00	32.92	0	−1.00	32.92	26.49
20	−1.13	32.98	25	−1.15	33.08	26.62
38	−1.27	33.25	50	−1.15	33.31	26.81
58	−1.09	33.32	75	−1.05	33.36	26.84
77	−1.04	33.36	100	−0.65	33.46	26.92
154	1.41	34.02	150	1.25	33.94	27.20
231	5.16	34.76	200	4.00	34.66	27.54
160	*1.42	34.13	300	3.45	34.63	27.56
264	3.09	34.55	400	4.45	34.85	27.64
391	4.45	34.85	600	3.85	34.86	27.71
721	3.65	34.86	(800)	3.55	34.86	27.74
			(1,000)	3.40	34.86	27.76

Station 2580; Apr. 7; latitude 44°22′ N., longitude 49°01′ W., depth 320 meters, dynamic height 971.017 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.74	32.92	0	−0.74	32.92	26.48
22	−0.75	32.92	25	−0.80	32.92	26.48
43	−1.42	33.13	50	−1.40	33.18	26.71
65	−1.34	33.24	75	−1.30	33.28	26.78
87	−1.27	33.33	100	−1.25	33.39	26.88
130	−1.16	-------	150	−0.50	33.62	27.04
173	0.27	33.74	200	0.80	33.90	27.19
260	1.87	34.36	(300)	2.45	34.66	27.68

Station 2581; Apr. 7; latitude 44°23′ N., longitude 49°07′ W., depth 90 meters. dynamic height 971.028 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.80	32.97	0	−0.80	32.97	26.52
27	−0.79	32.98	25	−0.80	32.98	26.53
58	−0.76	33.09	50	−0.75	33.06	26.59
89	−0.67	33.27	75	−0.70	33.19	26.70

Station 2582; Apr. 7; latitude 44°24′ N., longitude 49°32′ W., depth 44 meters, dynamic height 971.028 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.42	33.03	0	−0.40	33.03	26.56
24	−0.43	32.96	25	−0.40	33.03	26.56
47	−0.42	33.03	(50)	−0.40	33.03	26.56

Station 2583; Apr. 10; latitude 45°00′ N., longitude 49°36′ W., depth 64 meters, dynamic height 971.113 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−1.07	32.98	0	−1.07	32.98	26.54
27	−1.09	32.97	25	−1.10	32.97	26.53
55	−1.08	32.97	50	−1.10	32.97	26.53

Station 2584; Apr. 10; latitude 44°54′ N., longitude 49°15′ W., depth 71 meters, dynamic height 970.114 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−1.15	32.94	0	−1.15	32.94	26.51
26	−1.16	32.96	25	−1.15	32.96	26.52
52	−1.12	32.97	50	−1.15	32.96	26.52

Station 2585; Apr. 10; latitude 44°51′ N., longitude 49°02′ W., depth 185 meters, dynamic height 971.108 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−1.17	32.98	0	−1.17	32.98	26.54
25	−1.20	33.01	25	−1.20	33.01	26.57
51	−1.14	33.10	50	−1.15	33.10	26.64
76	−1.12	33.13	75	−1.10	33.13	26.66
102	−1.11	33.29	100	−1.10	33.28	26.78
153	−0.84	33.46	150	−0.85	33.45	26.91

Station 2586; Apr. 10; latitude 44°50′ N., longitude 48°58′ W., depth 823 meters, dynamic height 971.072 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−1.16	33.06	0	−1.16	33.06	26.61
25	−1.18	33.07	25	−1.18	33.07	26.62
50	−0.93	33.21	50	−0.93	33.21	26.73
76	−0.86	33.23	75	−0.85	33.23	26.73
101	−0.88	33.23	100	−0.90	33.23	26.74
151	−0.19	33.62	150	−0.20	33.61	27.02
202	0.82	34.03	200	0.80	34.01	27.28
303	1.59	34.26	300	1.55	34.25	27.42
402	2.46	34.53	400	2.45	34.52	27.57
600	3.60	34.77	600	3.60	34.77	27.67
			(800)	3.65	34.85	27.72

Station 2587; Apr. 10; latitude 44°48′ N., longitude 48°50′ W., depth 1,600 meters, dynamic height 970.980 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.41	33.36	0	−0.41	33.36	26.82
25	1.28	33.70	25	1.28	33.70	27.00
50	3.31	34.02	50	3.31	34.02	27.10
75	5.19	34.30	75	5.19	34.30	27.12
100	5.20	34.30	100	5.20	34.30	27.12
150	1.16	33.99	150	1.16	33.99	27.24
201	1.57	34.26	200	1.55	34.26	27.43
301	4.32	34.73	300	4.30	34.73	27.56
401	4.48	34.87	400	4.45	34.87	27.66
596	4.21	34.90	600	4.20	34.90	27.71
789	3.66	34.86	800	3.65	34.86	27.73
989	3.54	34.86	1,000	3.55	34.86	27.74
1,393	3.40	34.86				

Station 2588; Apr. 10; latitude 44°44′ N., longitude 48°31′ W., depth 2,424 meters, dynamic height 970.977 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	5.57	34.24	0	5.57	34.24	27.03
21	5.56	34.24	25	5.55	34.24	27.03
42	5.59	34.25	50	5.65	34.26	27.03
64	5.88	34.32	75	6.15	34.38	27.06
85	6.32	34.40	100	6.20	34.40	27.07
128	5.90	34.38	150	5.75	34.41	27.14
170	5.64	34.44	200	5.15	34.51	27.29
255	4.06	34.65	300	4.05	34.73	27.58
267	4.06	34.67	400	4.00	34.85	27.69
422	4.00	34.86	600	3.75	34.89	27.74
590	3.74	34.89	800	3.50	34.87	27.76
778	3.52	34.87	1,000	3.45	34.87	27.76
1,202	3.32	34.87				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2589; Apr. 10; latitude 44°47′ N., longitude 47°50′ W., depth 3,246 meters, dynamic height 971.008 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	11.12	35.32	0	11.12	35.32	27.02
22	11.23	35.335	25	11.20	35.33	27.01
44	11.12	35.32	50	11.15	35.32	27.02
65	11.12	35.33	75	11.10	35.32	27.03
87	11.13	35.325	100	11.10	35.33	27.03
130	11.19	35.34	150	9.85	35.12	27.09
174	8.05	34.95	200	6.95	34.88	27.35
261	5.43	34.78	300	5.35	34.83	27.52
267	5.74	34.86	400	5.00	34.92	27.64
446	4.86	34.94	600	4.40	34.93	27.70
657	4.23	34.92	800	3.90	34.91	27.75
821	3.82	34.92	1,000	3.55	34.89	27.76
1,150	3.38	34.88				

Station 2590; Apr. 11; latitude 44°52′ N., longitude 46°46′ W., depth 3,630 meters, dynamic height 970.996 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	10.81	35.22	0	10.81	35.22	27.00
18	10.83	35.20	25	10.80	35.21	27.00
35	10.74	35.21	50	10.65	35.17	26.99
53	10.57	35.15	75	9.70	35.05	27.06
70	9.83	35.06	100	9.40	34.97	27.05
105	9.32	34.95	150	8.30	34.80	27.09
141	8.67	34.83	200	6.32	34.74	27.33
211	5.97	34.75	300	5.80	34.88	27.50
197	6.46	34.73	400	5.30	34.93	27.60
284	5.61	34.86	(600)	3.45	34.86	27.75
366	*6.58	34.94	(800)	3.35	34.87	27.77
439	4.40	34.91	(1,000)	3.30	34.88	27.78
566	3.48	34.86				

Station 2591; Apr. 27; latitude 46°27′ N., longitude 48°56′ W., depth 66 meters, dynamic height 971.104 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.11	32.86	0	0.11	32.86	26.40
26	0.08	32.88	25	0.10	32.88	26.42
52	−0.60	32.89	50	−0.50	32.89	26.44

Station 2592; Apr. 27; latitude 46°16′ N., longitude 48°38′ W., depth 88 meters, dynamic height 971.101 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.06	32.87	0	−0.06	32.87	26.41
27	−0.21	32.88	25	−0.15	32.88	26.42
53	−0.38	32.98	50	−0.35	32.96	26.49
80	−1.12	33.12	75	−0.90	33.10	26.63

Station 2593; Apr. 27; latitude 46°01′ N., longitude 48°18′ W., depth 110 meters, dynamic height 971.095 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.23	32.94	0	−0.23	32.94	26.47
25	−0.24	32.94	25	−0.24	32.94	26.47
51	−0.90	33.01	50	−0.85	33.01	26.55
76	−1.16	33.23	75	−1.15	33.23	26.74
102	−1.04	33.35	100	−1.05	33.34	26.82

Station 2594; Apr. 28; latitude 45°56′ N., longitude 48°08′ W., depth 165 meters, dynamic height 971.105 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.73	32.91	0	−0.73	32.91	26.47
26	−0.73	32.89	25	−0.73	32.89	26.46
51	−0.73	32.91	50	−0.72	32.90	26.46
77	−1.47	33.10	75	−1.45	33.09	26.63
103	−1.36	33.22	100	−1.35	33.20	26.72
154	−1.39	33.37	150	−1.40	33.35	26.84

Station 2595; Apr. 28; latitude 45°52′ N., longitude 47°59′ W., depth 631 meters, dynamic height 971.058 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.32	32.97	0	−0.32	32.97	26.50
26	−0.90	33.06	25	−0.90	33.06	26.59
53	−1.23	33.28	50	−1.20	33.26	26.76
79	−1.34	33.44	75	−1.30	33.43	26.91
105	−1.79	33.50	100	−1.75	33.49	26.97
158	−0.86	33.56	150	−0.95	33.55	27.00
211	0.18	33.84	200	−0.05	33.78	27.14
316	2.73	34.33	300	2.55	34.27	27.36
384	*2.20	34.53	400	2.35	34.57	27.61
576	3.70	34.83	(600)	3.70	34.84	27.71

Station 2596; Apr. 28; latitude 45°49′ N., longitude 47°54′ W., depth 1,187 meters, dynamic height 971.048 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.63	32.95	0	−0.63	32.95	26.47
25	−0.43	33.00	25	−0.43	33.00	26.53
51	−0.63	33.27	50	−0.60	33.25	26.73
76	−1.31	33.41	75	−1.30	33.41	26.89
101	−0.57	33.60	100	−0.65	33.60	27.03
152	0.78	33.96	150	0.70	33.93	27.22
203	1.99	34.22	200	1.95	34.21	27.36
304	1.64	34.28	300	1.65	34.27	27.43
392	*2.34	34.51	400	2.35	34.52	27.57
590	3.15	34.71	600	3.20	34.72	27.66
789	3.88	34.86	800	3.90	34.86	27.70
989	3.67	34.88	1,000	3.65	34.88	27.74

Station 2597; Apr. 28; latitude 45°44′ N., longitude 47°44′ W., depth 1,500 meters, dynamic height 971.042 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.53	33.07	0	−0.53	33.07	26.59
24	−1.17	33.13	25	−1.15	33.15	26.68
49	3.35	33.91	20	3.35	33.92	27.00
73	3.34	34.02	75	3.35	34.02	27.09
97	3.06	34.00	100	3.05	34.01	27.10
146	4.00	34.19	150	4.15	34.24	27.19
195	6.12	34.67	200	6.15	34.69	27.31
292	5.76	34.81	300	5.60	34.80	27.46
393	2.16	34.45	400	2.15	34.45	27.54
587	3.11	34.69	600	3.20	34.70	27.65
780	3.82	34.85	800	3.85	34.86	27.70
977	3.60	34.88	1,000	3.60	34.88	27.75
1,374	3.46	34.89				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2598; Apr. 28; latitude 45°24′ N., longitude 47°15′ W., depth 2,880 meters, dynamic height 970.914 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.15	34.48	0	7.15	34.48	27.01
24	7.15	34.49	25	7.15	34.49	27.02
47	6.64	34.56	50	6.55	34.56	27.15
71	5.51	34.47	75	5.35	34.46	27.22
94	4.57	34.39	100	4.45	34.39	27.27
141	3.83	34.43	150	3.85	34.45	27.38
189	3.84	34.56	200	3.85	34.60	27.50
283	4.15	34.82	300	4.10	34.82	27.65
325	3.99	34.83	400	3.80	34.84	27.70
497	3.62	34.87	600	3.50	34.88	27.76
676	3.43	34.88	800	3.35	34.89	27.78
859	3.34	34.89	1,000	3.30	34.89	27.79
1,241	3.22	34.88				

Station 2599; Apr. 28; latitude 45°20′ N., longitude 46°32′ W., depth 3,182 meters, dynamic height 971.941 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.61	34.50	0	7.61	34.50	26.96
23	7.66	34.52	25	7.65	34.52	26.97
44	6.90	34.48	50	7.00	34.50	27.05
67	7.56	34.66	75	7.50	34.67	27.11
88	7.48	34.68	100	6.90	34.62	27.16
133	4.99	34.42	150	5.30	34.53	27.29
178	5.88	34.72	200	5.45	34.77	27.46
266	4.40	34.84	300	4.30	34.86	27.68
468	3.96	34.91	400	4.05	34.90	27.72
691	3.72	34.91	600	3.85	34.91	27.75
907	3.58	34.91	800	3.65	34.91	27.77
1,394	3.30	34.89	1,000	3.50	34.91	27.79

Station 2600; Apr. 28; latitude 45°15′ N., longitude 45°49′ W., depth 3,402 meters, dynamic height 970.955 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.83	34.50	0	7.83	34.50	26.92
21	7.84	34.52	25	7.85	34.51	26.93
41	7.81	34.51	50	7.80	34.51	26.94
62	7.77	34.54	75	6.80	34.47	27.05
82	6.10	34.44	100	5.80	34.47	27.18
123	-------	34.54	150	5.40	34.63	27.36
164	5.38	34.68	200	5.45	34.82	27.50
246	5.55	34.96	300	5.05	34.93	27.64
264	5.23	34.92	400	4.65	34.94	27.70
453	4.49	34.95	600	4.20	34.93	27.74
679	4.06	34.92	800	3.80	34.91	27.76
891	3.61	34.91	1,000	3.55	34.90	27.77
1,367	3.47	34.88				

Station 2601; Apr. 29; latitude 44°39′ N., longitude 45°41′ W., depth 3,704 meters, dynamic height 971.059 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	10.65	35.15	0	10.65	35.15	26.97
26	10.67	35.14	25	10.65	35.15	26.97
51	10.67	35.14	50	10.65	35.15	26.96
77	10.65	35.14	75	10.65	35.15	26.97
102	10.49	35.13	100	10.50	35.14	27.00
152	10.27	-------	150	10.25	35.14	27.04
203	9.29	35.14	200	9.40	35.14	27.19
305	6.80	34.96	300	6.95	34.96	27.42
332	6.39	34.96	400	5.85	34.96	27.56
532	5.02	34.94	600	4.65	34.93	27.69
754	4.00	34.92	800	3.95	34.92	27.75
974	3.86	34.91	1,000	3.85	34.91	27.75
1,453	3.39	34.89				

Station 2602; Apr. 29; latitude 44°02′ N., longitude 45°41′ W., depth 3,932 meters, dynamic height 971.191 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	14.21	35.87	0	14.21	35.87	26.84
31	14.21	35.87	25	14.20	35.87	26.84
61	14.19	35.86	50	14.20	35.87	26.84
92	13.81	35.80	75	14.10	35.85	26.84
122	12.88	35.61	100	13.60	35.76	26.88
183	12.55	35.58	150	12.70	35.60	26.94
245	11.17	35.28	200	12.15	35.51	26.98
367	9.35	35.17	300	10.35	35.22	27.09
483	7.03	34.98	400	8.80	35.12	27.27
723	4.44	34.93	600	5.35	34.95	27.61
959	3.67	34.91	800	4.10	34.92	27.74
1,204	3.42	34.88	1,000	3.60	34.90	27.77
1,699	3.31	34.88				

Station 2603; Apr. 29; latitude 44°14′ N., longitude 46°35′ W., depth 3,695 meters, dynamic height 971.054 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.12	34.38	0	8.12	34.38	26.79
24	8.06	34.40	25	8.05	34.41	26.83
49	9.40	34.88	50	9.40	34.89	26.99
73	9.31	34.89	75	9.30	34.89	27.01
98	8.78	34.80	100	8.65	34.78	27.03
147	7.36	34.60	150	7.30	34.60	27.08
195	6.61	34.59	200	6.60	34.60	27.18
293	6.85	34.90	300	6.75	34.89	27.39
360	4.45	34.66	400	4.40	34.71	27.53
547	4.41	34.89	600	4.35	34.92	27.71
740	4.04	34.94	800	3.90	34.93	27.77
937	3.73	34.91	(1,000)	3.70	34.91	27.77

Station 2604; Apr. 29; latitude 44°34′ N., longitude 47°33′ W., depth 3,585 meters, dynamic height 971.959 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.31	34.56	0	7.31	34.56	27.05
25	7.35	34.56	25	7.35	34.56	27.05
50	7.35	34.55	50	7.35	34.55	27.04
75	7.42	34.59	75	7.42	34.59	27.07
100	6.74	34.53	100	6.74	34.53	27.11
150	3.69	34.34	150	3.69	34.34	27.32
200	3.75	34.54	200	3.75	34.54	27.47
300	5.01	34.91	300	5.01	34.91	27.62
392	4.46	34.87	400	4.45	34.87	27.66
588	4.11	34.92	600	4.10	34.92	27.74
784	3.80	34.91	800	3.80	34.91	27.76
982	3.62	34.91	1,000	3.60	34.91	27.78
1,380	3.38	34.89				

Station 2605; Apr. 30; latitude 44°44′ N., longitude 48°18′ W., depth 2,871 meters, dynamic height 970.955 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.39	34.75	0	8.39	34.75	27.04
25	8.43	34.77	25	8.43	34.77	27.05
50	8.51	34.79	50	8.51	34.79	27.06
76	7.93	34.74	75	7.95	34.74	27.10
101	8.11	34.80	100	8.10	34.80	27.12
151	6.44	34.72	150	6.45	34.72	27.30
201	6.19	34.89	200	6.20	34.89	27.47
302	5.02	34.88	300	5.10	34.88	27.59
393	4.64	34.92	400	4.65	34.92	27.68
588	4.08	34.94	600	4.05	34.94	27.76
782	3.79	34.90	800	3.75	34.91	27.76
984	3.60	34.92	1,000	3.60	34.92	27.79
1,394	3.31	34.89				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2606; Apr. 30; latitude 44°51′ N., longitude 48°43′ W., depth 1,463 meters, dynamic height 970.926 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.18	34.54	0	7.18	34.54	27.06
25	7.20	54.54	25	7.20	34.54	27.06
50	7.20	34.54	50	7.20	34.54	27.06
75	7.23	34.56	75	7.23	34.56	27.06
100	5.94	34.48	100	5.94	34.48	27.17
150	4.63	34.57	150	4.63	34.57	27.40
199	4.50	34.75	200	4.50	34.75	27.55
299	4.37	34.88	300	4.35	34.88	27.68
367	4.11	34.91	400	4.00	34.91	27.74
552	3.69	34.89	600	3.65	34.88	27.75
737	3.55	34.88	800	3.55	34.88	27.76
928	3.56	34.88	1,000	3.50	34.88	27.77
1,319	3.40	34.89				

Station 2607; Apr. 30; latitude 44°56′ N., longitude 49°00′ W., depth 622 meters, dynamic height 971.060 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	10.46	35.19	0	10.46	35.19	27.05
26	10.44	35.18	25	10.45	35.18	27.04
52	-------	35.18	50	10.40	35.18	27.05
77	-------	35.14	75	10.10	35.14	27.07
103	-------	34.95	100	9.30	34.97	27.07
155	7.80	34.78	150	7.95	34.80	27.15
207	5.77	34.50	200	5.95	34.52	27.20
310	4.23	34.40	300	4.35	34.40	27.29
376	3.57	34.42	400	3.55	34.45	27.41
569	3.68	34.80	(600)	3.70	34.83	27.71

Station 2608; Apr. 30; latitude 44°58′ N., longitude 49°06′ W., depth 157 meters, dynamic height 971.102 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.14	33.00	0	−0.14	33.00	26.53
25	−0.71	33.08	25	−0.71	33.08	26.61
51	−0.65	33.12	50	−0.65	33.11	26.63
76	−0.09	33.34	75	−0.10	33.33	26.78
101	3.24	34.02	100	3.05	34.00	27.10
147	5.48	34.34	(150)	5.50	34.35	27.12

Station 2609; Apr. 30; latitude 45°01′ N., longitude 49°18′ W., depth 66 meters, dynamic height 971.120 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.12	33.00	0	0.12	33.00	26.52
27	−0.37	32.99	25	−0.35	32.99	26.52
55	−0.56	33.03	50	−0.55	33.02	26.56

Station 2610; Apr. 30; latitude 45°05′ N., longitude 49°38′ W., depth 59 meters, dynamic height 971.119 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.74	33.02	0	0.74	33.02	26.50
28	−0.02	33.02	25	0.00	33.02	26.54
50	−0.35	33.05	50	−0.35	33.05	26.57

Station 2611; Apr. 30; latitude 44°19′ N., longitude 49°40′ W., depth 44 meters, dynamic height 971.094 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.45	33.02	0	0.45	33.02	26.52
22	0.39	33.02	25	0.40	33.02	26.52
39	0.39	33.02				

Station 2612; Apr. 30; latitude 44°14′ N., longitude 49°18′ W., depth 119 meters, dynamic height 971.084 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.29	33.18	0	0.29	33.18	26.65
27	−0.21	33.22	25	−0.20	33.22	26.71
54	−0.03	33.28	50	−0.05	33.27	26.74
82	0.19	33.31	75	0.10	33.30	26.76
109	0.63	33.41	100	0.45	33.37	26.79

Station 2613; Apr. 30; latitude 44°09′ N., longitude 49°00′ W., depth 320 meters, dynamic height 971.028 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	10.15	35.14	0	10.15	35.14	27.06
25	9.90	35.10	25	9.90	35.10	27.06
50	-------	35.01	50	9.25	35.01	27.11
74	7.32	34.64	75	7.30	34.63	27.11
99	6.17	34.47	100	6.15	34.47	27.14
149	6.31	34.57	150	6.30	34.57	27.20
198	4.53	34.38	200	4.45	34.38	27.27
297	3.08	34.40	300	3.05	34.40	27.42

Station 2614; May 1; latitude 44°07′ N., longitude 48°50′ W., depth 1,454 meters, dynamic height 970.972 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.69	34.61	0	7.69	34.61	27.03
25	9.05	34.92	25	9.05	34.92	27.07
50	8.90	34.88	50	8.90	34.88	27.06
76	9.27	34.98	75	9.25	34.97	27.08
101	9.34	34.98	100	9.35	34.98	27.07
151	5.27	34.50	150	5.30	34.50	27.26
201	4.50	34.58	200	4.50	34.57	27.42
302	4.46	34.78	300	4.50	34.77	27.57
400	4.23	34.88	400	4.25	34.88	27.69
598	4.25	34.93	600	4.25	34.93	27.73
796	3.88	34.91	800	3.85	34.91	27.75
995	3.65	34.91	1,000	3.65	34.91	27.77
1,395	3.39	34.88				

Station 2615; May 1; latitude 44°01′ N., longitude 48°23′ W., depth 3,155 meters, dynamic height 970.945 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.48	34.28	0	6.48	34.28	26.94
25	6.22	34.28	25	6.22	34.28	26.98
50	5.99	34.36	50	5.99	34.36	27.07
76	5.86	34.41	75	5.90	34.41	27.12
101	4.78	34.32	100	4.80	34.32	27.18
151	3.91	34.40	150	3.95	34.40	27.34
202	3.16	34.41	200	3.15	34.41	27.42
303	4.05	34.73	300	4.05	34.73	27.59
397	4.10	34.88	400	4.10	34.88	27.71
594	3.76	34.90	600	3.75	34.90	27.75
791	3.48	34.90	800	3.50	34.90	27.78
991	3.37	34.88	1,000	3.35	34.89	27.79
1,395	3.21	34.89				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2616; May 1; latitude 43°53′ N., longitude 47°49′ W., depth 3,612 meters, dynamic height 971.000 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.74	34.73	0	8.74	34.73	26.97
25	9.69	34.98	25	9.69	34.98	27.01
50	10.01	35.06	50	10.01	35.06	27.02
74	10.22	35.17	75	10.20	35.17	27.07
99	10.05	35.15	100	10.05	35.15	27.08
149	9.64	35.10	150	9.60	35.10	27.12
199	8.09	35.02	200	8.05	35.02	27.31
298	5.99	34.91	300	5.95	34.91	27.51
364	4.87	34.87	400	4.60	34.87	27.64
545	4.16	34.93	600	4.10	34.93	27.75
724	4.00	34.92	800	3.85	34.91	27.75
916	3.62	34.90	1,000	3.50	34.90	27.78
1,313	3.38	34.89				

Station 2617; May 1; latitude 43°42′ N., longitude 46°57′ W., depth 4,070 meters, dynamic height 971.132 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.17	35.70	0	13.17	35.70	26.91
25	13.16	35.70	25	13.16	35.70	26.92
50	13.16	35.70	50	13.16	35.70	26.92
74	13.14	35.70	75	13.15	35.70	26.92
99	12.98	35.66	100	12.95	35.66	26.93
149	12.04	35.48	150	12.05	35.48	26.98
199	11.93	35.45	200	11.95	35.46	26.98
298	9.37	35.18	300	9.30	35.18	27.23
342	8.45	35.09	400	7.45	35.02	27.39
507	5.77	34.95	600	5.10	34.96	27.65
669	4.74	34.975	800	3.95	34.90	27.73
846	3.76	34.89	1,000	3.60	34.88	27.76
1,209	3.46	34.88				

Station 2618; May 1; latitude 43°30′ N., longitude 46°04′ W., depth 4,490 meters, dynamic height 971.448 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	16.06	36.23	0	16.06	36.23	26.70
34	16.08	36.23	25	16.10	36.23	26.70
67	16.08	36.24	50	16.10	36.24	26.70
101	16.06	36.24	75	16.10	36.24	26.70
135	16.01	36.24	100	16.05	36.24	26.71
202	16.09	36.24	150	16.05	36.24	26.71
269	16.09	36.24	200	16.05	36.24	26.71
404	*13.46	35.67	300	15.65	36.15	26.73
420	13.14	35.67	400	13.60	35.75	26.87
633	8.29	35.10	600	8.90	35.16	27.28
845	5.37	34.97	800	5.80	34.99	27.60
1,070	4.21	34.945	1,000	4.45	34.95	27.72
1,533	3.51	34.905				

Station 2619; May 2; latitude 42°54′ N., longitude 46°11′ W., depth 4,397 meters, dynamic height 971.334 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	15.39	36.12	0	15.39	36.12	26.76
38	15.39	36.12	25	15.40	36.12	26.76
76	15.38	36.11	50	15.40	36.12	26.76
114	15.28	36.10	75	15.40	36.12	26.76
152	15.19	36.08	100	15.30	36.10	26.77
227	13.84	35.81	150	15.20	36.08	26.78
303	12.55	35.56	200	14.30	35.92	26.85
455	10.02	35.24	300	12.65	35.57	26.92
471	9.72	35.20	400	10.95	35.36	27.09
711	5.00	34.84	600	6.90	34.94	27.41
953	4.49	34.98	800	4.75	34.87	27.62
1,195	3.76	34.91	1,000	4.35	34.97	27.75
1,685	3.54	34.92				

Station 2620; May 2; latitude 42°20′ N., longitude 46°22′ W., depth 4,408 meters, dynamic height 971.254 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	17.12	36.24	0	17.12	36.24	26.46
27	17.04	36.22	25	17.05	36.22	26.47
53	15.38	36.00	50	15.55	36.01	26.64
80	14.81	35.92	75	14.90	35.93	26.73
106	14.39	35.85	100	14.45	35.87	26.78
160	13.90	35.77	150	14.00	35.79	26.82
213	12.77	35.54	200	13.10	35.61	26.86
319	10.01	35.12	300	10.30	35.16	27.05
372	9.54	35.15	400	9.10	35.13	27.23
572	5.74	34.94	600	5.55	34.94	27.59
799	4.69	34.97	800	4.70	34.97	27.71
1,018	4.17	34.945	1.000	4.20	34.95	27.75
1,474	3.63	34.925				

Station 2621; May 2; latitude 42°33′ N., longitude 47°02′ W., depth 3,923 meters, dynamic height 971.195 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	15.61	36.07	0	15.61	36.07	26.67
30	15.63	36.08	25	15.63	36.08	26.67
59	14.21	35.83	50	14.80	35.92	26.74
90	13.17	35.63	75	13.55	35.69	26.83
119	12.76	35.55	100	13.00	35.61	26.88
178	11.70	35.34	150	12.15	35.43	26.92
238	11.20	35.29	200	11.50	35.32	26.96
357	8.96	35.10	300	10.10	35.20	27.11
452	6.93	34.96	400	8.05	35.02	27.31
680	4.99	34.96	600	5.35	34.96	27.62
910	4.39	34.98	800	4.65	34.97	27.72
1,153	3.97	34.96	1,000	4.20	34.97	27.77
1,660	3.48	34.91				

Station 2622; May 2; latitude 42°51′ N., longitude 47°45′ W., depth 3,475 meters, dynamic height 971.090 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.36	35.61	0	13.36	35.61	26.80
24	13.31	35.62	25	13.30	35.62	26.83
48	13.14	35.60	50	13.10	35.59	26.84
73	12.76	35.53	75	12.70	35.51	26.87
97	12.03	35.41	100	11.95	35.39	26.92
145	9.96	35.05	150	9.70	35.02	27.04
193	8.19	34.80	200	8.15	34.80	27.11
290	8.01	35.04	300	7.75	35.02	27.35
329	6.99	34.94	400	5.80	34.91	27.53
493	5.00	34.91	600	4.70	34.93	27.68
658	4.52	34.94	800	4.15	34.94	27.74
835	4.05	34.94	1,000	3.85	34.93	27.77
1,204	3.74	34.93				

Station 2623; May 3; latitude 43°07′ N., longitude 48°27′ W., depth 2,533 meters, dynamic height 970.921 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.27	34.16	0	6.27	34.16	26.87
25	5.80	34.22	25	5.80	34.22	26.99
50	6.26	34.39	50	6.26	34.39	27.06
75	6.17	34.45	75	6.17	34.45	27.11
100	5.10	34.45	100	5.10	34.45	27.25
150	4.58	34.57	150	4.58	34.57	27.40
201	4.70	34.73	200	4.70	34.73	27.52
301	4.86	34.91	300	4.85	34.91	27.64
377	4.29	34.91	400	4.20	34.91	27.72
568	3.83	34.90	600	3.80	34.90	27.75
759	3.63	34.90	800	3.60	34.90	27.77
952	3.42	34.89	1,000	3.40	34.89	27.78
1,343	3.33	34.88				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2624; May 3; latitude 43°24′ N., longitude 49°04′ W., depth 1,463 meters, dynamic height 970.977 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	4.97	34.11	0	4.97	34.11	26.99
26	5.25	34.23	25	5.25	34.23	27.06
51	5.13	34.30	50	5.15	34.30	27.12
77	6.52	34.53	75	6.55	34.52	27.13
103	6.31	34.57	100	6.30	34.56	27.19
154	6.50	34.76	150	6.50	34.76	27.32
205	3.37	34.47	200	3.70	34.48	27.43
308	2.50	34.50	300	2.50	34.48	27.54
399	3.58	34.76	400	3.60	34.76	27.66
596	3.76	34.84	600	3.75	34.84	27.70
790	3.83	34.87	800	3.80	34.87	27.72
986	3.68	34.87	1,000	3.65	34.87	27.74
1,374	3.45	34.89				

Station 2625; May 3; latitude 42°38′ N., longitude 49°03′ W., depth 2,469 meters, dynamic height 970.961 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.85	33.88	0	6.85	33.88	26.58
25	5.82	33.97	25	5.82	33.97	26.79
51	5.49	34.08	50	5.50	34.08	26.91
76	4.76	34.22	75	4.75	34.22	27.11
101	4.69	34.26	100	4.70	34.26	27.15
152	4.45	34.52	150	4.45	34.48	27.35
203	5.65	34.86	200	5.65	34.84	27.50
304	4.66	34.87	300	4.65	34.87	27.64
405	4.80	34.94	400	4.80	34.94	27.68
604	4.24	34.96	600	4.25	34.96	27.75
801	3.96	34.94	800	3.95	34.94	27.77
1,000	3.73	34.93	1,000	3.75	34.93	27.78
1,394	3.50	34.92				

Station 2626; May 3; latitude 42°12′ N., longitude 48°24′ W., depth 3,329 meters, dynamic height 971.071 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	14.33	35.79	0	14.33	35.79	26.75
23	14.02	35.78	25	14.00	35.78	26.81
47	13.79	35.77	50	13.70	35.76	26.86
70	13.32	35.68	75	13.20	35.66	26.88
93	12.39	35.50	100	12.15	35.43	26.92
140	10.55	35.16	150	10.35	35.14	27.03
187	9.69	35.08	200	9.35	35.03	27.11
280	6.36	34.73	300	6.15	34.76	27.37
374	5.58	34.93	400	5.45	34.95	27.60
565	4.61	34.96	600	4.55	34.96	27.72
759	4.26	34.95	800	4.15	34.95	27.75
951	3.85	34.93	1,000	3.80	34.92	27.76
1,339	3.46	34.89				

Station 2627; May 4; latitude 41°32′ N., longitude 47°25′ W., depth 4,106 meters, dynamic height 971.146 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.41	35.66	0	13.41	35.66	26.84
28	13.42	35.66	25	13.40	35.66	26.84
54	13.29	35.61	50	13.30	35.63	26.84
82	12.39	35.50	75	12.60	35.53	26.91
109	12.11	35.47	100	12.20	35.48	26.95
163	10.69	35.18	150	10.95	35.23	26.99
217	10.40	35.20	200	10.50	35.20	27.04
326	7.88	34.99	300	8.40	35.02	27.25
423	6.98	34.98	400	7.20	34.98	27.40
652	5.02	34.97	600	5.50	34.97	27.62
892	4.23	34.96	800	4.50	34.97	27.73
1,129	3.85	34.94	1,000	4.05	34.95	27.76
1,624	3.41	34.91				

Station 2628; May 4; latitude 41°03′ N., longitude 48°35′ W., depth 2,853 meters, dynamic height 971.198 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.93	35.74	0	13.93	35.74	26.78
29	13.67	35.72	25	13.70	35.72	26.83
56	13.67	35.72	50	13.65	35.72	26.84
84	13.53	35.70	75	13.60	35.71	26.84
112	12.83	35.62	100	13.05	35.66	26.91
169	12.56	35.58	150	12.65	35.59	26.94
225	12.27	35.52	200	12.40	35.56	26.97
337	9.08	35.09	300	9.85	35.20	27.15
463	7.17	34.97	400	8.05	35.01	27.30
692	5.06	34.96	600	5.75	34.96	27.57
918	4.49	34.97	800	4.70	34.96	27.70
1,143	3.96	34.95	1,000	4.25	34.97	27.76
1,588	3.71	34.93				

Station 2629; May 4; latitude 41°52′ N., longitude 49°16′ W.; depth 3,127 meters, dynamic height 971.137 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.23	35.59	0	13.23	35.59	26.82
25	12.97	35.57	25	12.97	35.57	26.86
51	12.84	35.57	50	12.84	35.57	26.89
76	12.81	35.57	75	12.80	35.57	26.90
101	12.79	35.57	100	12.80	35.57	26.90
152	11.42	35.33	150	11.50	35.34	26.97
203	10.27	35.14	200	10.30	35.14	27.03
304	8.44	35.04	300	8.50	35.04	27.25
403	6.93	34.97	400	7.00	34.97	27.42
602	4.64	34.88	600	4.65	34.87	27.64
798	4.45	34.97	800	4.45	34.96	27.73
998	4.08	34.95	1,000	4.05	34.95	27.76
1,396	3.60	34.91				

Station 2630; May 5; latitude 41°03′ N., longitude 49°57′ W.; depth 3,594 meters, dynamic height 971.410 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	18.89	36.44	0	18.95	36.44	26.15
25	18.90	36.44	25	18.95	36.44	26.15
50	19.00	36.44	50	18.95	36.44	26.15
76	17.90	36.31	75	17.95	36.32	26.31
101	16.67	36.17	100	16.70	36.18	26.51
151	15.99	36.13	150	16.00	36.13	26.63
202	14.94	35.96	200	15.00	35.96	26.73
303	12.92	35.54	300	13.00	35.55	26.84
358	12.20	35.48	400	11.35	35.36	27.01
536	8.25	35.06	600	7.15	35.04	27.45
714	*5.86	35.02	800	5.10	34.98	27.67
893	4.49	34.95	1,000	4.20	34.95	27.75
1,247	3.88	34.94				

Station 2631; May 5; latitude 41°33′ N., longitude 49°56′ W.; depth 2,880 meters, dynamic height 971.086 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.72	33.01	0	3.72	33.01	26.26
25	5.12	33.88	25	5.12	33.88	26.81
49	8.69	34.71	50	8.70	34.71	26.96
74	8.47	34.69	75	8.45	34.68	26.98
98	6.66	34.41	100	6.65	34.42	27.03
147	-------	35.33	150	10.65	35.33	27.12
196	------	35.23	200	9.60	35.22	27.21
294	7.94	35.05	300	7.85	35.04	27.35
401	6.53	34.99	400	6.55	34.99	27.49
600	4.60	34.91	600	4.60	34.91	27.67
799	4.33	34.97	800	4.35	34.96	27.74
998	4.01	34.95	1,000	4.00	34.95	27.77
1,393	3.58	34.92				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2632; May 5; latitude 42°11′ N., longitude 49°41′ W.; depth 3,219 meters, dynamic height 971.038 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.00	35.59	0	13.00	35.59	26.87
24	12.91	35.58	25	12.90	35.58	26.89
49	12.74	35.55	50	12.75	35.55	26.89
73	12.45	35.49	75	12.45	35.48	26.90
98	11.43	35.33	100	11.35	35.32	26.98
147	10.32	35.17	150	10.25	35.16	27.05
195	9.17	35.07	200	9.00	35.06	27.19
293	4.76	34.67	300	4.75	34.69	27.48
371	5.22	34.90	400	5.05	34.90	27.61
557	4.16	34.90	600	4.10	34.90	27.72
742	4.00	34.92	800	3.95	34.93	27.76
932	3.89	34.94	1,000	3.85	34.94	27.77
1,317	3.53	34.91				

Station 2633; May 5; latitude 42°32′ N., longitude 49°45′ W.; depth 2,908 meters, dynamic height 970.941 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.06	33.89	0	6.06	33.89	26.69
25	5.73	33.91	25	5.73	33.91	26.75
50	4.15	34.01	50	4.16	34.01	27.01
74	4.18	34.18	75	4.20	34.18	27.14
99	4.23	34.32	100	4.25	34.33	27.25
149	4.35	34.57	150	4.35	34.57	27.43
199	4.35	34.73	200	4.35	34.73	27.56
298	4.53	34.87	300	4.55	34.87	27.65
344	4.45	34.89	400	4.30	34.90	27.69
524	4.03	34.91	600	3.95	34.92	27.75
710	3.89	34.92	800	3.75	34.91	27.76
899	3.67	34.91	1,000	3.60	34.91	27.78
1,288	3.43	34.90				

Station 2634; May 5; latitude 42°51′ N., longitude 49°47′ W.; depth 1,600 meters, dynamic height 970.997 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	4.92	34.09	0	4.92	34.09	26.98
22	4.97	34.10	25	5.00	34.11	26.99
45	7.51	34.44	50	7.70	34.59	27.01
67	-------	34.86	75	8.55	34.83	27.08
89	8.14	34.79	100	8.10	34.80	27.12
134	7.88	34.83	150	7.55	34.83	27.23
179	6.89	34.83	200	6.35	34.80	27.37
268	4.56	34.67	300	3.85	34.65	27.55
367	3.19	34.65	400	3.30	34.67	27.62
559	3.86	34.84	600	3.85	34.85	27.70
757	3.83	34.87	800	3.80	34.87	27.73
952	3.71	34.90	1,000	3.70	34.90	27.76
1,349	3.40	34.87				

Station 2635; May 5; latitude 42°56′ N., longitude 49°52′ W., depth 622 meters, dynamic height 971.023 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.40	33.56	0	2.40	33.56	26.81
23	6.65	34.43	25	6.70	34.47	27.07
46	-------	34.68	50	7.95	34.72	27.09
69	8.34	34.84	75	8.25	34.78	27.09
92	5.11	34.33	100	5.10	34.34	27.16
138	5.23	34.43	150	5.35	34.46	27.23
184	5.61	34.53	200	5.60	34.56	27.28
276	5.46	34.71	300	4.65	34.65	27.46
346	2.94	34.52	400	3.00	34.54	27.54
534	3.23	34.68	(600)	3.30	34.74	27.67

Station 2636; May 5; latitude 43°03′ N., longitude 49°56′ W.; depth 157 meters, dynamic height 971.063 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.57	33.09	0	0.57	33.09	26.56
24	0.52	33.11	25	0.50	33.11	26.57
49	0.39	33.42	50	0.40	33.44	26.85
73	2.24	33.87	75	2.35	33.88	27.07
98	3.27	34.03	100	3.40	34.05	27.11
142	4.25	34.27	(150)	4.30	34.30	27.22

Station 2637; May 6; latitude 43°07′ N., longitude 49°59′ W., depth 88 meters, dynamic height 971.066 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.57	33.05	0	0.57	33.05	26.53
25	0.49	33.08	25	0.49	33.08	26.55
49	0.67	33.43	50	0.70	33.44	26.83
74	1.51	33.71	75	1.55	33.72	27.00

Station 2638; May 6; latitude 43°22′ N., longitude 50°08′ W.; depth 66 meters, dynamic height 971.072 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	1.90	33.20	0	1.90	33.20	26.57
26	1.87	33.21	25	1.90	33.21	26.58
53	0.38	33.25	50	0.40	33.24	26.69

Station 2639; May 6; latitude 43°07′ N., longitude 50°31′ W., depth 89 meters, dynamic height 971.072 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	1.24	33.12	0	1.24	33.12	26.54
25	1.18	33.14	25	1.18	33.14	26.57
50	0.27	33.37	50	0.27	33.37	26.80
75	0.74	33.57	75	0.74	33.57	26.94

Station 2640; May 6; latitude 42°57′ N., longitude 50°44′ W.; depth 631 meters, dynamic height 971.066 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.66′	33.11	0	0.66	33.11	26.57
25	0.19	33.13	25	0.19	33.13	26.61
50	0.03	33.43	50	0.03	33.43	26.87
75	2.51	33.89	75	2.51	33.89	27.06
101	2.67	33.95	100	2.65	33.95	27.10
151	3.79	34.13	150	3.80	34.12	27.13
201	4.06	34.20	200	4.05	34.20	27.17
302	3.28	34.42	300	3.30	34.42	27.42
404	2.99	34.51	400	3.00	34.51	27.52
602	3.06	34.65	600	3.05	34.65	27.62

Station 2641; May 6; latitude 42°51′ N., longitude 50°54′ W., depth 1,463 meters, dynamic height 971.003 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.42	33.47	0	2.42	33.47	26.74
25	8.09	34.71	25	8.09	34.71	27.05
50	-------	34.96	50	9.15	34.96	27.08
75	8.19	34.79	75	8.19	34.79	27.10
100	6.47	34.50	100	6.47	34.50	27.12
150	4.46	34.39	150	4.46	34.39	27.27
199	3.48	34.40	200	3.45	34.40	27.38
299	2.69	34.53	300	2.70	34.53	27.56
386	2.93	34.65	400	3.00	34.66	27.64
576	3.73	34.81	600	3.75	34.82	27.69
763	3.75	34.86	800	3.75	34.87	27.73
956	3.69	34.88	1,000	3.70	34.90	27.76
1,345	3.48	34.89				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2642; May 6; latitude 42°25′ N., longitude 51°29′ W., depth 2,816 meters, dynamic height 971.029 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.93	33.13	0	2.93	33.13	26.42
25	1.59	33.26	25	1.59	33.26	26.64
51	0.29	33.36	50	0.30	33.36	26.79
76	0.31	33.45	75	0.30	33.45	26.86
101	0.37	33.56	100	0.35	33.56	26.95
152	1.61	33.98	150	1.55	33.96	27.19
203	2.62	34.22	200	2.55	34.20	27.31
304	3.30	34.57	300	3.25	34.56	27.53
397	4.05	34.78	400	4.05	34.78	27.63
598	3.90	34.86	600	3.90	34.86	27.71
802	3.72	34.88	800	3.75	34.88	27.74
1,002	3.59	34.89	1,000	3.60	34.89	27.77
1,403	3.38	34.88				

Station 2643; May 6; latitude 41°58′ N., longitude 51°58′ W., depth 3,797 meters, dynamic height 971.224 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	15.07	35.92	0	15.07	35.92	26.68
23	15.00	35.91	25	15.00	35.91	26.69
46	14.73	35.88	50	14.70	35.87	26.73
69	14.62	35.86	75	14.60	35.85	26.73
92	14.40	35.82	100	14.30	35.80	26.76
138	13.71	35.70	150	13.40	35.63	26.82
184	12.63	35.48	200	12.45	35.47	26.89
276	11.61	35.42	300	10.85	35.31	27.06
306	10.58	35.30	400	8.55	35.12	27.31
445	7.75	35.07	600	5.40	34.96	27.62
574	5.65	34.97	800	4.55	34.94	27.71
742	4.69	34.94	1,000	4.15	34.94	27.75
1,108	3.99	34.94				

Station 2644; May 7; latitude 42°32′ N., longitude 52°′ 46′ W., depth 3,804 meters, dynamic height 971.188 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.99	35.70	0	13.99	35.70	26.75
25	14.02	35.70	25	14.02	35.70	26.75
50	14.34	35.77	50	14.34	35.77	26.73
74	14.41	35.85	75	14.40	35.85	26.78
99	13.10	35.55	100	13.05	35.54	26.82
149	12.23	35.40	150	12.25	35.40	26.87
198	11.69	35.34	200	11.65	35.34	26.94
297	10.12	35.22	300	10.05	35.21	27.13
351	9.04	35.14	400	8.10	35.09	27.36
520	6.17	35.00	600	5.30	34.96	27.63
685	4.61	34.93	800	4.15	34.92	27.73
875	3.97	34.91	1,000	3.80	34.91	27.76
1,277	3.61	34.90				

Station 2645; May 7; latitude 42°52′ N., longitude 52°16′ W., depth 2,880 meters, dynamic height 971.109 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	5.93	33.38	0	5.93	33.38	26.31
25	5.57	33.41	25	5.57	33.41	26.37
50	8.45	34.46	50	8.45	34.46	26.80
74	9.36	34.75	75	9.40	34.75	26.88
99	10.01	34.94	100	10.00	34.94	26.93
149	9.17	34.88	150	9.15	34.88	27.02
198	8.90	34.98	200	8.85	34.98	27.15
297	7.27	34.94	300	7.20	34.93	27.36
371	4.82	34.69	400	4.35	34.69	27.53
560	3.32	34.70	600	3.40	34.73	27.66
751	3.94	34.87	800	3.90	34.87	27.72
944	3.71	34.87	1,000	3.70	34.87	27.74
1,334	3.51	34.89				

Station 2646; May 7; latitude 43°16′ N., longitude 51°49′ W., depth 1,463 meters, dynamic height 971.065 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	1.26	33.04	0	1.26	33.04	26.48
25	0.57	33.10	25	0.57	33.10	26.57
50	0.68	33.20	50	0.68	33.20	26.64
74	2.94	33.75	75	3.10	33.76	26.91
99	8.31	34.77	100	8.30	34.77	27.07
149	6.77	34.54	150	6.75	34.54	27.12
199	5.51	34.44	200	5.50	34.44	27.20
298	2.48	34.34	300	2.50	34.34	27.43
403	2.91	34.58	400	2.90	34.57	27.58
602	3.61	34.79	600	3.60	34.79	27.69
800	3.85	34.87	800	3.85	34.87	27.72
1,000	3.71	34.87	1,000	3.70	34.87	27.74
1,399	3.48	34.88				

Station 2647; May 7; latitude 43°25′ N., longitude 51°39′ W., depth 595 meters, dynamic height 971.109 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.84	32.80	0	3.84	32.80	26.08
25	1.37	33.10	25	1.37	33.10	26.52
50	−0.62	33.21	50	−0.62	33.21	26.71
76	−0.75	33.27	75	−0.75	33.27	26.76
101	−0.50	33.41	100	−0.50	33.41	26.87
151	−0.04	33.62	150	−0.05	33.62	27.02
201	0.58	33.85	200	0.60	33.85	27.16
302	1.80	34.12	300	1.80	34.11	27.30
400	2.49	34.44	400	2.50	34.44	27.51
577	3.61	34.76	(600)	3.65	34.78	27.67

Station 2648; May 7; latitude 43°29′ N., longitude 51°34′ W., depth 167 meters, dynamic height 971.104 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.76	32.74	0	3.76	32.74	26.04
25	2.97	32.79	25	2.97	32.79	26.15
51	1.42	33.04	50	1.50	33.03	26.46
76	0.38	33.29	75	0.40	33.28	26.72
102	0.00	33.58	100	0.00	33.56	26.97
153	2.20	34.07	150	2.00	34.05	27.23

Station 2649; May 7; latitude 43°36′ N., longitude 51°28′ W., depth 88 meters, dynamic height 971.102 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.76	32.67	0	3.76	32.67	25.98
27	2.58	32.90	25	2.65	32.89	26.26
53	1.20	33.14	50	1.35	33.11	26.53
80	0.67	33.30	75	0.75	33.27	26.70

Station 2650; May 24; latitude 47°09′ N., longitude 48°38′ W., depth 89 meters, dynamic height, 971.061 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	1.76	32.65	0	1.76	32.65	26.14
26	0.80	32.69	25	0.80	32.69	26.23
51	−0.16	32.79	50	−0.10	32.79	26.35
77	−1.38	33.12	75	−1.25	33.10	26.64

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2651; May 24; latitude 47°07′ N., longitude 48°11′ W., depth 133 meters, dynamic height, 971.061 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.13	32.66	0	2.13	32.66	26.12
25	0.82	32.66	25	0.82	32.66	26.21
50	−0.86	32.80	50	−0.86	32.80	26.39
76	−1.52	33.07	75	−1.50	33.06	26.62
101	−1.33	33.21	100	−1.35	33.20	26.73

Station 2652; May 24; latitude 47°06′ N., longitude 47°53′ W., depth 165 meters, dynamic height 971.056 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.10	32.64	0	2.10	32.64	26.10
26	0.78	32.64	25	0.80	32.64	26.19
51	−1.13	32.95	50	−1.05	32.94	26.51
77	−1.57	33.13	75	−1.55	33.12	26.67
103	−1.56	33.23	100	−1.55	33.22	26.75
154	−0.42	33.58	150	−0.50	33.54	26.98

Station 2653; May 24; latitude 47°05′ N., longitude 47°12′ W., depth 622 meters, dynamic height 970.993 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.27	32.95	0	2.27	32.95	26.34
25	0.61	32.97	25	0.61	32.97	26.46
50	−0.53	33.26	50	−0.53	33.26	26.75
76	−1.41	33.40	75	−1.40	33.39	26.88
101	−0.63	33.71	100	−0.70	33.70	27.11
151	0.49	34.00	150	0.45	33.99	27.29
201	1.37	34.26	200	1.35	34.25	27.44
302	2.42	34.52	300	2.40	34.51	27.57
398	2.97	34.68	400	3.00	34.68	27.66
596	3.61	34.84	600	3.60	34.84	27.73

Station 2654; May 24; latitude 47°04′ N., longitude 46°55′ W., depth 1,097 meters, dynamic height 970.944 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.61	33.05	0	2.61	33.05	26.39
25	−0.09	33.23	25	−0.09	33.23	26.71
50	−1.07	33.52	50	−1.07	33.52	26.98
76	0.43	33.85	75	0.45	33.84	27.17
101	0.47	34.01	100	0.45	34.00	27.29
151	1.58	34.27	150	1.55	34.26	27.43
202	2.34	34.47	200	2.30	34.46	27.54
303	3.11	34.69	300	3.10	34.68	27.65
404	3.44	34.78	400	3.45	34.77	27.68
604	3.58	34.86	600	3.60	34.86	27.74
803	3.56	34.88	800	3.55	34.88	27.76
1,005	3.44	34.90	1,000	3.45	34.90	27.78

Station 2655; May 24; latitude 47°03′ N., longitude 46°38′ W., depth 631 meters, dynamic height 970.888 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.67	33.37	0	3.67	33.37	26.54
25	1.63	33.54	25	1.63	33.54	26.86
50	1.82	33.98	50	1.82	33.98	27.19
74	2.37	34.32	75	2.35	34.33	27.43
99	2.38	34.41	100	2.35	34.41	27.49
149	2.30	34.48	150	2.30	34.48	27.56
198	2.82	34.62	200	2.85	34.63	27.63
297	3.61	34.77	300	3.65	34.78	27.67
384	4.01	34.89	400	4.00	34.90	27.73
583	3.67	34.91	(600)	3.65	34.91	27.77

Station 2656; May 24; latitude 47°02′ N., longitude 46°00′ W., depth 256 meters, dynamic height 970.908 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.06	34.16	0	6.06	34.16	26.91
25	5.12	34.14	25	5.12	34.14	27.01
51	4.87	34.16	50	4.90	34.16	27.04
76	4.56	34.21	75	4.60	34.21	27.12
102	4.13	34.25	100	4.20	34.24	27.19
153	3.58	34.56	150	3.60	34.55	27.49
204	3.60	34.71	200	3.60	34.70	27.61

Station 2657; May 24–25; latitude 46°58′ N., longitude 45°29′ W., depth 220 meters, dynamic height 970.895 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.81	34.22	0	6.81	34.22	26.86
26	5.72	34.30	25	5.75	34.30	27.05
51	5.71	34.31	50	5.75	34.31	27.06
77	4.74	34.31	75	4.80	34.31	27.17
102	3.91	34.44	100	4.00	34.42	27.35
154	3.45	34.63	150	3.45	34.62	27.56
205	3.82	34.76	200	3.80	34.75	27.63

Station 2658; May 25; latitude 46°57′ N., longitude 45°14′ W., depth 165 meters, dynamic height 970.900 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.40	34.24	0	6.40	34.24	26.93
26	5.51	34.25	25	5.55	34.25	27.04
52	5.02	34.28	50	5.10	34.28	27.12
77	4.48	34.27	75	4.50	34.27	27.18
103	4.54	34.33	100	4.55	34.32	27.21
155	3.63	34.62	150	3.70	34.59	27.52

Station 2659; May 25; latitude 46°53′ N., longitude 44°51′ W., depth 135 meters, dynamic height 970.893 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.76	34.20	0	6.76	34.20	26.84
24	5.64	34.22	25	5.65	34.22	27.00
48	5.11	34.26	50	5.10	34.27	27.11
72	4.67	34.30	75	4.65	34.30	27.18
96	4.15	34.42	100	4.05	34.45	27.37

Station 2660; May 25; latitude 46°43′ N., longitude 44°52′ W., depth 165 meters, dynamic height 970.875 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.72	34.19	0	6.72	34.19	26.84
25	4.85	34.30	25	4.85	34.30	27.16
51	4.32	34.34	50	4.40	34.33	27.24
76	4.01	34.54	75	4.05	34.54	27.44
102	3.88	34.60	100	3.90	34.59	27.50
153	3.93	34.64	150	3.95	34.64	27.53

Station 2661; May 25; latitude 46°36′ N., longitude 44°52′ W., depth 220 meters, dynamic height 970.876 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.39	34.18	0	6.39	34.18	26.88
25	5.17	34.24	25	5.17	34.24	27.08
51	4.57	34.33	50	4.60	34.32	27.21
76	3.83	34.46	75	3.90	34.46	27.39
102	3.36	34.52	100	3.40	34.51	27.48
153	3.08	34.62	150	3.10	34.61	27.59
204	3.56	34.77	200	3.55	34.75	27.65

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2662; May 25; latitude 46°30′ N., longitude 44°52′ W., depth 622 meters, dynamic height 970.867 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.61	34.28	0	6.61	34.28	26.92
25	5.72	34.31	25	5.72	34.31	27.07
51	5.09	34.44	50	5.15	34.43	27.23
76	4.40	34.52	75	4.45	34.52	27.38
101	3.75	34.58	100	3.80	34.57	27.49
152	3.38	34.72	150	3.40	34.71	27.64
203	3.55	34.81	200	3.55	34.81	27.70
304	3.76	34.88	300	3.75	34.88	27.74
403	3.67	34.88	400	3.70	34.88	27.75
602	3.58	34.88	600	3.60	34.88	27.76

Station 2663; May 25; latitude 46°26′ N., longitude 44°52′ W., depth 1,829 meters, dynamic height 970.864 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.23	34.24	0	7.23	34.24	26.80
25	5.44	34.32	25	5.44	34.32	27.10
50	5.47	34.50	50	5.47	34.50	27.24
76	4.72	34.56	75	4.75	34.56	27.37
101	4.72	34.68	100	4.70	34.68	27.47
151	3.94	34.74	150	3.95	34.74	27.60
201	3.56	34.76	200	3.55	34.76	27.65
302	3.69	34.86	300	3.70	34.86	27.72
402	3.61	34.89	400	3.65	34.89	27.75
603	3.54	34.90	600	3.55	34.90	27.77
804	3.47	34.89	800	3.45	34.90	27.78
1,004	3.39	34.90	1,000	3.40	34.90	27.79
1,403	3.30	34.91				

Station 2664; May 25; latitude 46°05′ N., longitude 44°52′ W., depth 3,438 meters, dynamic height 970.958 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	9.97	34.60	0	9.97	34.60	26.66
25	8.60	34.60	25	8.60	34.60	26.89
49	8.18	34.59	50	8.15	34.59	26.95
74	7.93	34.69	75	7.90	34.69	27.06
98	6.68	34.61	100	6.65	34.61	27.17
147	6.46	34.79	150	6.45	34.80	27.36
197	6.72	34.97	200	6.70	34.97	27.45
295	4.93	34.85	300	4.90	34.85	27.59
400	4.64	34.93	400	4.65	34.93	27.68
600	4.08	34.94	600	4.10	34.94	27.75
799	3.75	34.93	800	3.75	34.93	27.77
999	3.64	34.93	1,000	3.65	34.93	27.78
1,398	3.35	34.91				

Station 2665; May 25; latitude 46°07′ N., longitude 45°25′ W., depth 2,241 meters, dynamic height 970.895 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.92	34.35	0	7.92	34.35	26.79
25	6.37	34.35	25	6.37	34.35	27.01
50	7.27	34.68	50	7.27	34.68	27.14
74	5.52	34.57	75	5.50	34.57	27.29
99	4.94	34.56	100	4.95	34.56	27.35
149	4.64	34.72	150	4.65	34.72	27.51
199	3.72	34.73	200	3.70	34.73	27.62
298	3.61	34.81	300	3.65	34.81	27.68
379	3.73	34.87	400	3.75	34.88	27.73
569	3.72	34.89	600	3.70	34.89	27.75
758	3.61	34.91	800	3.55	34.91	27.77
951	3.42	34.90	1,000	3.40	34.90	27.79
1,339	3.27	34.90				

Station 2666; May 25; latitude 46°10′ N., longitude 46°04′ W., depth 906 meters, dynamic height 970.879 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	5.60	33.98	0	5.60	33.98	26.82
25	4.36	34.01	25	4.36	34.01	26.97
50	3.31	34.19	50	3.31	34.19	27.23
75	2.94	34.41	75	2.94	34.41	27.43
100	2.99	34.49	100	2.99	34.49	27.50
150	3.53	34.67	150	3.53	34.67	27.58
201	3.69	34.75	200	3.70	34.75	27.64
301	3.86	34.86	300	3.85	34.86	27.70
402	3.91	34.89	400	3.95	24.89	27.72
602	3.62	34.88	600	3.65	34.89	27.75
802	3.42	34.89	800	3.45	34.89	27.77

Station 2667; May 26; latitude 46°13′ N., longitude 46°39′ W., depth 558 meters, dynamic height 970.852 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.50	33.62	0	3.50	33.62	26.75
24	2.49	34.45	25	2.55	34.45	27.51
47	2.63	34.49	50	2.65	34.49	27.53
71	2.76	34.57	75	2.80	34.58	27.58
94	2.99	34.62	100	3.00	34.63	27.61
141	3.11	34.65	150	3.25	34.67	27.61
188	4.29	34.86	200	4.30	34.87	27.67
283	4.20	34.89	300	4.20	34.89	27.70
377	4.08	34.91	(400)	4.05	34.91	27.72

Station 2668; May 26; latitude 46°14′ N., longitude 47°00′ W., depth 1,152 meters, dynamic height 970.862 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.98	33.88	0	3.98	33.88	26.91
24	3.15	33.98	25	3.15	33.99	27.08
49	3.04	34.34	50	3.05	34.39	27.41
73	3.34	34.52	75	3.35	34.53	27.49
97	3.53	34.64	100	3.55	34.65	27.57
146	3.41	34.71	150	3.40	34.71	27.63
194	3.40	34.75	200	3.40	34.75	27.67
291	3.65	34.83	300	3.70	34.84	27.71
357	3.76	34.87	400	3.75	34.88	27.73
542	3.68	34.89	600	3.65	34.89	27.75
731	3.57	34.90	800	3.55	34.90	27.77
916	3.57	34.89	(1,000)	3.55	34.90	27.77

Station 2669; May 26; latitude 46°16′ N., longitude 47°23′ W., depth 622 meters, dynamic height 970.929 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	1.41	32.91	0	1.41	32.91	26.36
25	−0.77	33.21	25	−0.77	33.21	26.71
51	−1.05	33.54	50	−1.05	33.53	26.98
76	0.09	33.83	75	0.05	33.83	27.18
102	0.64	34.05	100	0.60	34.02	27.29
153	3.71	34.57	150	3.55	34.54	27.48
204	3.98	34.73	200	4.00	34.73	27.59
306	2.90	34.69	300	2.90	34.69	27.67
401	3.65	34.83	400	3.65	34.83	27.70
603	3.70	34.88	600	3.70	34.88	27.74

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2670; May 26; latitude 46°19′ N., longitude 47°51′ W., depth 165 meters, dynamic height 971.039 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	1.83	32.68	0	1.83	32.68	26.14
25	0.08	32.94	25	0.08	32.94	26.46
51	−1.63	33.19	50	−1.60	33.17	26.70
76	−1.54	33.31	75	−1.55	33.31	26.81
102	−0.97	33.49	100	−1.05	33.48	26.94
153	−0.30	33.67	150	−0.35	33.66	27.05

Station 2671; May 26; latitude 46°20′ N., longitude 48°11′ W., depth 110 meters, dynamic height 971.055 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.81	32.71	0	2.81	32.71	26.09
25	1.03	32.77	25	1.03	32.77	26.28
50	−0.41	32.93	50	−0.41	32.93	26.47
76	−1.25	33.23	75	−1.25	33.23	26.74
101	−1.00	33.37	100	−1.00	33.36	26.84

Station 2672; May 26; latitude 46°21′ N., longitude 48°33′ W., depth 88 meters, dynamic height 971.058 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.11	32.77	0	3.11	32.77	26.12
26	1.32	32.79	25	1.40	32.79	26.26
52	−0.19	32.92	50	−0.05	32.89	26.42
78	−0.93	33.17	75	−0.90	33.15	26.67

Station 2673; May 26; latitude 46°24′ N., longitude 48°54′ W., depth 64 meters, dynamic height 971.057 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.44	32.79	0	3.44	32.79	26.10
26	1.51	32.77	25	1.60	32.77	26.24
53	−0.38	33.06	50	−0.10	33.03	26.54

Station 2674; May 26; latitude 46°11′ N., longitude 48°34′ W., depth 88 meters, dynamic height 971.061 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.83	32.78	0	3.83	32.78	26.06
25	1.26	32.78	25	1.26	32.78	26.26
51	−0.03	32.91	50	0.00	32.90	26.43
76	−0.92	33.19	75	−0.90	33.18	26.70

Station 2675; May 26; latitude 45°56′ N., longitude 48°13′ W., depth 110 meters, dynamic height 971.055 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.63	32.68	0	2.63	32.68	26.08
26	0.61	32.76	25	0.70	32.76	26.28
51	−1.44	33.09	50	−1.40	33.05	26.60
77	−1.38	33.24	75	−1.40	33.23	26.75
103	−1.08	33.35	100	−1.10	33.34	26.82

Station 2676; May 26; latitude 45°51′ N., longitude 48°06′ W., depth 165 meters, dynamic height 971.050 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.34	32.69	0	2.34	32.69	26.11
25	0.31	32.96	25	0.31	32.96	26.46
51	−1.57	33.10	50	−1.55	33.10	26.65
76	−1.62	33.21	75	−1.60	33.21	26.73
102	−1.46	33.29	100	−1.50	33.28	26.79
153	−1.15	33.45	150	−1.15	33.44	26.92

Station 2677; May 26; latitude 45°46′ N., longitude 47°58′ W., depth 622 meters, dynamic height 971.073 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.26	32.63	0	2.26	32.63	26.08
25	0.15	32.82	25	0.15	32.82	26.36
51	−1.67	33.17	50	−1.65	33.17	26.70
76	−1.62	33.24	75	−1.60	33.24	26.76
101	−1.55	33.38	100	−1.55	33.36	26.86
152	−0.34	33.65	150	−0.40	33.64	27.05
203	−0.16	33.73	200	−0.20	33.72	27.10
304	1.53	34.27	300	1.45	34.24	27.42
403	2.44	34.51	400	2.40	34.50	27.56
602	3.74	34.87	600	3.70	34.87	27.73

Station 2678; May 27; latitude 45°42′ N., longitude 47°52 W., depth 1,097 meters, dynamic height 971.049 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.03	32.63	0	2.03	32.63	26.10
25	−1.56	33.06	25	−1.56	33.06	26.61
50	−1.63	33.23	50	−1.63	33.23	26.75
76	−1.06	33.44	75	−1.10	33.44	26.91
101	−0.67	33.59	100	−0.70	33.59	27.02
151	−0.19	33.69	150	−0.20	33.69	27.08
202	0.18	33.82	200	0.15	33.81	27.15
303	1.27	34.23	300	1.20	34.22	27.42
404	2.23	34.47	400	2.20	34.46	27.55
604	3.81	34.88	600	3.80	34.88	27.73
804	3.66	34.89	800	3.65	34.89	27.75
1,008	3.56	34.90	1,000	3.55	34.90	27.77

Station 2679; May 27; latitude 45°37′ N., longitude 47°45′ W., depth 1,408 meters, dynamic height 971.000 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.43	32.73	0	2.43	32.73	26.13
25	−0.62	33.03	25	−0.62	33.03	26.56
50	−1.61	33.38	50	−1.61	33.38	26.87
76	−1.25	33.53	75	−1.30	33.53	26.99
101	−0.39	33.71	100	−0.45	33.71	27.10
151	0.55	34.01	150	0.55	34.01	27.29
202	1.26	34.20	200	1.20	34.19	27.40
303	2.64	34.54	300	2.60	34.53	27.56
387	2.89	34.66	400	2.95	34.67	27.64
577	3.74	34.85	600	3.75	34.85	27.71
763	3.72	34.87	800	3.70	34.87	27.73
955	3.62	34.89	1,000	3.60	34.89	27.76
1,338	3.37	34.90				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2680; May 27; latitude 45°20′ N., longitude 47°21′ W., depth 2,963 meters, dynamic height 970.886 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	2.37	33.09	0	2.37	33.09	26.43
25	2.49	33.82	25	2.49	33.82	27.00
50	1.11	33.94	50	1.11	33.94	27.20
75	1.95	34.27	75	1.95	34.27	27.41
101	2.73	34.44	100	2.70	34.43	27.47
151	2.65	34.53	150	2.65	34.53	27.56
201	2.94	34.63	200	2.90	34.63	27.62
302	3.32	34.75	300	3.30	34.74	27.67
403	4.18	34.92	400	4.20	34.92	27.72
604	3.62	34.91	600	3.65	34.91	27.76
805	3.48	34.91	800	3.50	34.90	27.78
1,004	3.41	34.91	1,000	3.40	34.90	27.79
1,402	3.32	34.90				

Station 2681; May 27; latitude 45°20′ N., longitude 46°38′ W., depth 3,246 meters, dynamic height 970.888 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	6.62	34.09	0	6.62	34.09	26.77
25	5.45	34.13	25	5.45	34.13	26.94
50	4.89	34.30	50	4.89	34.30	27.15
75	4.45	34.42	75	4.45	34.42	27.29
100	3.96	34.56	100	3.96	34.56	27.45
150	3.63	34.66	150	3.63	34.66	27.56
200	3.58	34.74	200	3.58	34.74	27.64
300	3.64	34.81	300	3.64	34.81	27.68
370	3.73	34.87	400	3.75	34.88	27.73
559	3.71	34.91	600	3.70	34.91	27.76
750	3.56	34.91	800	3.50	34.91	27.78
942	3.43	34.91	1,000	3.40	34.91	27.79
1,329	3.31	34.91				

Station 2682; May 27; latitude 46°20′ N., longitude 45°55′ W., depth 3,383 meters, dynamic height 970.899 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	8.43	34.36	0	8.43	34.36	26.72
25	6.41	34.33	25	6.41	34.33	26.99
50	6.75	34.60	50	6.75	34.60	27.16
75	6.01	34.67	75	6.01	34.67	27.31
100	5.24	34.62	100	5.24	34.62	27.36
150	5.12	34.76	150	5.12	34.76	27.49
200	4.58	34.81	200	4.58	34.81	27.58
300	3.76	34.81	300	3.76	34.81	27.67
389	3.79	34.87	400	3.80	34.88	27.73
586	3.73	34.91	600	3.70	34.91	27.76
784	3.55	34.90	800	3.55	34.90	27.77
981	3.43	34.91	1,000	3.40	34.91	27.79
1,378	3.28	34.91				

Station 2683; May 27; latitude 44°52′ N., longitude 45°55′ W., depth 3,457 meters, dynamic height 970.952 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	8.48	34.39	0	8.48	34.39	26.74
25	7.91	34.39	25	7.91	34.31	26.76
49	7.88	34.54	50	7.90	34.54	26.95
74	7.61	34.59	75	7.60	34.59	27.03
99	6.74	34.54	100	6.70	34.54	27.12
148	5.12	34.49	150	5.00	34.49	27.29
197	3.40	34.54	200	3.40	34.55	27.51
296	4.55	34.85	300	4.55	34.85	27.63
368	4.36	34.91	400	4.30	34.92	27.70
553	4.09	34.94	600	3.95	34.93	27.75
740	3.64	34.90	800	3.60	34.90	27.77
932	3.51	34.90	1,000	3.50	34.90	27.78
1,323	3.31	34.89				

Station 2684; May 27; latitude 44°21′ N., longitude 45°55′ W., depth 3,722 meters, dynamic height 971.057 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	9.20	33.98	0	9.20	33.98	26.30
22	11.44	34.81	25	11.45	34.87	26.61
45	-------	35.10	50	11.45	35.08	26.78
67	-------	34.85	75	9.20	34.83	26.97
90	8.57	34.78	100	8.15	34.73	27.05
135	7.40	34.62	150	7.30	34.62	27.09
179	7.14	34.65	200	7.00	34.70	27.20
269	6.64	34.85	300	4.55	34.62	27.44
299	4.52	34.62	400	4.75	34.85	27.61
456	4.84	34.97	600	4.50	34.93	27.69
618	4.45	34.93	800	3.90	34.93	27.76
788	3.91	34.93	1,000	3.70	34.93	27.78
1,149	3.65	34.93				

Station 2685; May 28; latitude 44°28′ N., longitude 46°45′ W., depth 3,667 meters, dynamic height 970.949 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.61	34.09	0	7.61	34.09	26.63
25	3.75	33.73	25	3.75	33.73	26.82
50	6.18	34.32	50	6.18	34.32	27.00
76	4.75	34.20	75	4.80	34.20	27.08
101	4.29	34.27	100	4.30	34.26	27.18
151	5.38	34.69	150	5.35	34.68	27.40
201	5.40	34.80	200	5.40	34.80	27.49
302	4.74	34.87	300	4.75	34.87	27.62
395	4.72	34.97	400	4.75	34.97	27.69
593	4.05	34.93	600	4.05	34.93	27.74
790	3.71	34.92	800	3.70	34.92	27.77
989	3.57	34.92	1,000	3.55	34.92	27.78
1,388	3.40	34.92				

Station 2686; May 28; latitude 44°34′ N., longitude 47°36′ W., depth 3,457 meters, dynamic height 970.942 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	4.82	33.52	0	4.82	33.52	26.54
25	4.62	33.83	25	4.62	33.83	26.81
50	5.18	34.21	50	5.18	34.21	27.04
74	4.26	34.18	75	4.20	34.18	27.13
99	3.57	34.21	100	3.55	34.21	27.22
149	6.04	34.78	150	6.05	34.78	27.39
199	5.40	34.80	200	5.40	34.80	27.49
298	4.88	34.89	300	4.85	34.89	27.62
374	4.01	34.85	400	3.95	34.85	27.69
565	3.88	34.91	600	3.85	34.92	27.75
758	3.73	34.93	800	3.65	34.93	27.78
952	3.47	34.90	1,000	3.45	34.90	27.78
1,346	3.35	34.91				

Station 2687; May 28; latitude 44°39′ N., longitude 48°08′ W., depth 2,999 meters, dynamic height 970.913 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.33	33.85	0	6.33	33.85	26.62
25	5.65	34.12	25	5.65	34.12	26.92
50	6.01	34.30	50	6.01	34.30	27.02
76	3.17	34.14	75	3.15	34.14	27.20
101	4.74	34.59	100	4.75	34.59	27.40
151	3.26	34.51	150	3.25	34.51	27.48
201	4.72	34.83	200	4.70	34.83	27.59
302	4.80	34.95	300	4.80	34.95	27.68
391	4.27	34.92	400	4.25	34.92	27.71
586	3.83	34.91	600	3.85	34.91	27.74
781	3.85	34.96	800	3.85	34.96	27.78
978	3.58	34.94	1,000	3.55	34.93	27.79
1,376	3.34	34.91				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2688; May 28; latitude 44°44′ N., longitude 48°43′ W., depth 1,463 meters, dynamic height 970.953 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.63	33.88	0	6.63	33 88	26.60
25	6.16	34.11	25	6.16	34.11	26.84
50	7.35	34.55	50	7.35	34.55	27.03
76	7.66	34.69	75	7.65	34.69	27.10
101	6.84	34.65	100	6.90	34.65	27.18
151	5.94	34.71	150	6.00	34.71	27.34
201	4.78	34.71	200	4.80	34.71	27.48
302	2.76	34.63	300	2.75	34.63	27.63
400	3.57	34.81	400	3.60	34.81	27.69
599	3.77	34.88	600	3.75	34.89	27.74
797	3.65	34.88	800	3.65	34.88	27.74
995	3.66	34.92	1,000	3.65	34.92	27.77
1,392	3.38	34.91				

Station 2689; May 28; latitude 44°46′ N., longitude 49°00′ W., depth 631 meters, dynamic height 971.056 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.20	32.61	0	2.20	32.61	26.06
25	−1.43	33.19	25	−1.43	33.19	26.71
50	−1.33	33.25	50	−1.33	33.25	26.76
76	−1.31	33.30	75	−1.30	33.30	26.80
101	−1.18	33.43	100	−1.20	33.43	26.91
151	−1.12	33.46	150	−1.15	33.47	26.94
202	−0.35	33.68	200	−0.40	33.66	27.06
303	2.05	34.39	300	2.00	34.37	27.48
399	2.58	34.54	400	2.60	34.54	27.57
601	3.66	34.87	600	3.65	34.87	27.73

Station 2690; May 28; latitude 44°47′ N., longitude 49°08′ W., depth 157 meters, dynamic height 971.060 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.14	32.66	0	3.14	32.66	26.03
26	0.10	32.93	25	0.15	32.93	26.45
51	−1.29	33.21	50	−1.25	33.20	26.72
77	−1.28	33.26	75	−1.25	33.26	26.76
103	−1.33	33.31	100	−1.35	33.30	26.80
154	−0.63	33.59	150	−0.70	33.56	26.99

Station 2691; May 28; latitude 44°49′ N., longitude 49°21′ W., depth 68 meters, dynamic height 971.065 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.28	32.84	0	3.28	32.84	26.16
25	1.41	32.89	25	1.41	32.89	26.34
50	−0.39	33.07	50	−0.39	33.07	26.59

Station 2692; May 28; latitude 44°51′ N., longitude 49°36′ W., depth 68 meters, dynamic height 971.063 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.61	32.94	0	3.61	32.94	26.20
26	1.51	32.99	25	1.60	32.99	26.41
52	−0.05	33.16	50	0.15	33.13	26.60

Station 2693; May 29; latitude 44°13′ N., longitude 49°30′ W., depth 46 meters, dynamic height 971.019 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	4.49	33.00	0	4.49	33.00	26.16
21	1.86	33.15	25	1.85	33.16	26.53
43	1.85	33.17				

Station 2694; May 29; latitude 44°05′ N., longitude 49°05′ W., depth 88 meters, dynamic height 971.015 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.58	32.56	0	2.58	32.56	25.99
26	−0.38	33.02	25	−0.30	33.01	26.53
51	−1.52	33.37	50	−1.50	33.35	26.85
77	−0.83	33.57	75	−0.85	33.56	26.99

Station 2695; May 29; latitude 44°03′ N., longitude 48°56′ W., depth 320 meters, dynamic height 971.001 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.35	32.56	0	2.35	32.56	26.01
23	0.07	33.15	25	0.00	33.17	26.65
46	−1.22	33.31	50	−1.20	33.35	26.84
68	−1.18	33.55	75	−0.95	33.62	27.05
91	−0.20	33.71	100	−0.05	33.75	27.12
137	0.41	33.91	150	0.85	33.99	27.26
183	1.77	34.23	200	1.85	34.29	27.43
274	2.03	34.42	(300)	2.10	34.45	27.54

Station 2696; May 29; latitude 44°01′ N., longitude 48°50′ W., depth 1,463 meters, dynamic height 970.971 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	2.92	32.80	0	2.92	32.80	26.15
20	1.79	33.41	25	1.40	33.44	26.79
41	−0.88	33.52	50	0.60	33.73	27.06
61	2.87	33.97	75	2.35	33.91	27.08
81	2.08	33.90	100	1.30	33.91	27.16
122	0.64	33.95	150	2.35	34.22	27.33
162	2.96	34.37	200	2.75	34.47	27.50
243	2.61	34.55	300	2.60	34.56	27.58
243	2.58	34.49	400	3.00	34.66	27.63
363	2.73	34.61	600	3.85	34.88	27.72
482	3.67	34.78	800	3.75	34.91	27.75
626	3.86	34.89	(1,000)	3.60	34.91	27.77
944	3.61	34.91				

Station 2697; May 29; latitude 43°55′ N., longitude 48°33′ W., depth 2,880 meters, dynamic height 970.948 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.87	33.73	0	6.87	33.73	26.45
22	7.55	34.09	25	7.55	34.13	26.67
45	6.63	34.31	50	6.65	34.34	26.96
67	6.66	34.43	75	6.20	34.44	27.10
89	5.60	34.45	100	5.25	34.47	27.24
134	4.66	34.53	150	4.75	34.60	27.41
179	4.98	34.73	200	4.95	34.77	27.51
268	4.95	34.87	300	4.95	34.92	27.63
322	4.95	34.95	400	4.70	34.96	27.69
494	4.40	34.95	600	4.25	34.97	27.75
674	4.11	34.97	800	3.85	34.94	27.77
857	3.71	34.93	1,000	3.50	34.92	27.79
1,243	3.40	34.92				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2698; May 29; latitude 43°44′ N., longitude 47°55′ W., depth 3,603 meters, dynamic height 970.964 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	7.64	33.96	0	7.64	33.96	26.52
24	7.86	34.25	25	7.85	34.26	26.73
47	6.66	34.35	50	6.45	34.35	27.00
71	5.53	34.33	75	5.35	34.32	27.11
95	4.34	34.22	100	4.35	34.23	27.15
142	5.35	34.57	150	5.55	34.63	27.33
189	6.50	34.91	200	6.30	34.89	27.44
284	4.54	34.79	300	4.45	34.80	27.60
348	4.38	34.85	400	4.30	34.89	27.68
529	4.23	34.95	600	4.15	34.95	27.75
716	3.96	34.94	800	3.85	34.93	27.76
905	3.74	34.93	1,000	3.65	34.93	27.78
1,297	3.39	34.92				

Station 2699; May 29; latitude 43°36′ N., longitude 47°01′W., depth 4,024 meters, dynamic height 971.106 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	14.00	35.53	0	14.00	35.53	26.61
24	14.04	35.52	25	14.05	35.52	26.59
49	13.22	35.58	50	13.20	35.58	26.82
73	12.97	35.58	75	12.95	35.58	26.86
97	12.22	35.42	100	12.15	35.42	26.90
146	11.87	35.43	150	11.80	35.42	26.97
194	10.36	35.19	200	10.25	35.18	27.06
291	8.42	35.06	300	8.25	35.05	27.29
380	6.80	34.99	400	6.50	34.98	27.49
572	4.75	34.96	600	4.60	34.96	27.70
766	4.08	34.95	800	4.05	34.95	27.76
961	3.95	34.95	1,000	3.90	34.95	27.78
1,355	3.50	34.91				

Station 2700; May 30; latitude 43°26′ N., longitude 45°58′ W., depth 4,344 meters, dynamic height 971.197 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	15.34	35.67	0	15.34	35.67	26.42
25	15.30	35.67	25	15.30	35.67	26.43
50	14.27	35.68	50	14.27	35.68	26.65
74	14.15	35.73	75	14.15	35.73	26.73
99	13.43	35.64	100	13.40	35.63	26.81
149	12.73	35.57	150	12.70	35.57	26.91
199	11.21	35.28	200	11.20	35.28	26.97
298	9.57	35.15	300	9.50	35.15	27.17
382	8.17	35.03	400	7.90	35.01	27.31
576	5.46	34.97	600	5.35	34.97	27.62
772	4.74	35.00	800	4.65	35.00	27.74
969	4.14	34.96	1,000	4.10	34.96	27.76
1,368	3.55	34.93				

Station 2701; May 30; latitude 42°57′ N., longitude 46°08′ W., depth 4,253 meters, dynamic height 971.228 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	15.57	35.61	0	15.57	35.61	26.32
25	15.56	35.61	25	15.56	35.61	26.34
49	15.10	35.92	50	15.10	35.92	26.67
74	13.90	35.70	75	13.90	35.70	26.76
99	13.58	35.67	100	13.55	35.67	26.81
147	12.53	35.51	150	12.50	35.50	26.90
197	12.15	35.48	200	12.10	35.48	26.96
295	10.56	35.25	300	10.40	35.24	27.09
396	8.24	34.99	400	8.15	34.99	27.26
593	5.65	34.96	600	5.65	34.96	27.58
790	4.68	34.98	800	4.65	34.98	27.72
989	4.13	34.95	1,000	4.10	34.96	27.76
1,386	3.75	34.96				

Station 2702; May 30; latitude 42°24′ N., longitude 46°09′ W., depth 4,463 meters, dynamic height 971.526 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	18.23	36.38	0	18.23	36.38	26.28
25	18.23	36.38	25	18.23	36.38	26.28
49	17.80	36.37	50	17.80	36.37	26.38
74	17.26	36.36	75	17.25	36.36	26.51
98	17.09	36.36	100	17.05	36.36	26.56
147	16.93	36.34	150	16.90	36.34	26.58
197	16.65	36.31	200	16.65	36.31	26.62
295	16.50	36.27	300	16.45	36.27	26.63
396	*15.10	36.00	400	15.00	35.98	26.74
592	10.04	35.25	600	9.90	35.23	27.16
			(800)	-------	------	27.52
			(1,000)	-------	------	27.73

Station 2703; May 30; latitude 42°31′ N., longitude 46°50′ W., depth 3,987 meters, dynamic height 971.230 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	16.34	35.88	0	16.34	35.88	26.35
23	16.58	35.91	25	16.55	35.94	26.36
46	16.37	36.24	50	16.30	36.23	26.64
68	15.80	36.15	75	15.65	36.12	26.70
91	15.26	36.05	100	15.05	36.01	26.76
137	14.32	35.86	150	14.15	35.85	26.83
183	13.78	35.80	200	13.40	35.68	26.85
274	10.01	35.05	300	9.85	35.09	27.07
317	9.69	35.12	400	7.80	35.00	27.32
490	5.98	34.92	600	5.15	34.92	27.61
673	4.88	34.93	800	4.60	34.97	27.71
856	4.44	34.98	1,000	4.00	34.97	27.78
1,239	3.63	34.95				

Station 2704; May 30; latitude 42°44′ N., longitude 47°39′ W., depth 3,429 meters, dynamic height 971.053 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	9.40	33.66	0	9.40	33.66	26.03
28	7.84	33.72	25	7.95	33.72	26.30
54	5.01	33.77	50	5.15	33.76	26.70
82	7.48	34.40	75	7.10	34.32	26.89
109	6.04	34.33	100	6.50	34.34	26.98
164	5.01	34.30	150	5.10	34.30	27.13
218	7.08	34.81	200	6.55	34.68	27.24
327	3.32	34.50	300	4.05	34.56	27.45
408	5.20	34.96	400	5.15	34.94	27.63
617	4.34	34.96	600	4.40	34.96	27.73
830	3.99	34.94	800	4.00	34.94	27.76
1,044	3.84	34.94	1,000	3.85	34.94	27.77
1,480	3.38	34.89				

Station 2705; May 31; latitude 42°57′ N., longitude 48°24′ W., depth 2,972 meters, dynamic height 970.944 meters

Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.79	33.98	0	8.79	33.98	26.37
28	6.94	34.06	25	7.00	34.05	26.69
55	6.77	34.30	50	6.85	34.27	26.88
82	5.88	34.39	75	6.20	34.37	27.04
109	4.58	34.40	100	4.80	34.40	27.24
165	4.65	34.68	150	4.60	34.62	27.43
219	4.83	34.81	200	4.80	34.78	27.54
328	4.54	34.91	300	4.65	34.90	27.66
408	4.27	34.90	400	4.30	34.90	27.69
614	3.82	34.91	600	3.85	34.91	27.75
825	3.59	34.92	800	3.60	34.92	27.78
1,038	3.43	34.92	1,000	3.45	34.92	27.79
1,469	3.31	34.91				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2706; May 31; latitude 43°11′ N., longitude 49°12′ W., depth 1,554 meters, dynamic height 970.951 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	4.80	33.43	0	4.80	33.43	26.48
25	6.13	34.16	25	6.13	34.16	26.89
50	6.37	34.40	50	6.37	34.42	27.06
76	6.24	34.58	75	6.25	34.58	27.21
101	3.06	34.27	100	3.10	34.27	27.31
151	3.95	34.51	150	3.95	34.51	27.42
202	3.09	34.52	200	3.15	34.52	27.50
303	2.67	34.60	300	2.65	34.59	27.61
380	2.84	34.68	400	2.95	34.70	27.67
567	3.86	34.86	600	3.85	34.87	27.71
752	3.79	34.90	800	3.75	34.90	27.75
942	3.67	34.90	1,000	3.65	34.90	27.76
1,325	3.56	34.91				

Station 2707; May 31; latitude 42°38′ N., longitude 49°12′ W., depth 2,058 meters, dynamic height 970.963 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.74	33.92	0	7.74	33.92	26.47
21	7.73	33.92	25	7.65	33.93	26.50
41	6.85	34.08	50	6.90	34.10	26.74
62	7.04	34.14	75	6.15	34.21	26.93
82	5.64	34.27	100	5.45	34.35	27.13
123	5.20	34.43	150	4.55	34.46	27.32
164	4.33	34.49	200	4.35	34.60	27.45
246	4.37	34.74	300	4.40	34.86	27.65
298	4.40	34.86	400	4.20	34.91	27.72
457	4.06	34.92	600	3.80	34.92	27.76
624	3.77	34.91	800	3.55	34.91	27.78
798	3.55	34.91	1,000	3.45	34.91	27.79
1,168	3.38	34.91				

Station 2708; May 31; latitude 42°19′ N., longitude 48°22′ W., depth 3,246 meters, dynamic height 971.000 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	11.15	34.41	0	11.15	34.41	26.31
28	9.41	34.13	25	9.50	34.14	26.38
56	8.93	34.77	50	9.05	34.75	26.93
84	5.32	34.26	75	5.95	34.41	27.11
111	6.04	34.47	100	5.70	34.38	27.12
168	4.31	34.36	150	4.65	34.38	27.24
224	4.18	34.53	200	4.20	34.45	27.35
335	4.99	34.88	300	4.80	34.80	27.56
443	4.54	34.93	400	4.75	34.92	27.65
662	4.17	34.95	600	4.25	34.95	27.74
880	4.00	34.94	800	4.05	34.95	27.76
1,100	3.75	34.95	1,000	3.85	34.95	27.78
1,538	3.41	34.92				

Station 2709; June 1; latitude 42°00′ N., longitude 47°31′ W., depth 3,658 meters, dynamic height 971.173 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	14.47	35.49	0	14.47	35.49	26.47
16	14.46	35.50	25	14.50	35.55	26.52
31	14.50	35.58	50	13.20	35.49	26.75
46	13.40	35.50	75	12.60	35.41	26.80
61	12.82	35.46	100	12.25	35.36	26.83
92	12.33	35.37	150	11.50	35.30	26.94
123	11.88	35.34	200	10.85	35.22	26.99
184	11.08	35.25	300	8.65	35.08	27.25
180	11.92	35.43	400	7.30	34.98	27.38
334	8.05	35.03	600	5.35	34.93	27.59
530	6.06	34.94	800	4.20	34.93	27.73
712	4.45	34.93	1,000	3.90	34.92	27.75
1,137	3.75	34.92				

Station 2710; June 1; latitude 41°47′ N., longitude 46°42′ W., depth 4,207 meters, dynamic height 971.181 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	14.26	35.25	0	14.26	35.25	26.35
18	14.28	35.25	25	14.30	35.38	26.43
35	14.29	35.53	50	14.20	35.72	26.71
53	14.17	35.73	75	13.80	35.66	26.75
70	13.87	35.67	100	13.55	35.66	26.80
106	13.43	35.66	150	11.40	35.27	26.93
141	11.48	35.28	200	11.20	35.26	26.95
211	11.08	35.24	300	9.85	35.18	27.13
203	11.25	35.28	400	7.60	34.99	27.34
328	9.22	35.14	600	4.85	34.98	27.69
469	6.22	34.92	800	4.40	34.98	27.74
636	4.70	34.99	1,000	4.20	34.97	27.76
1,030	4.15	34.97				

Station 2711; June 2; latitude 41°19′ N., longitude 48°31′ W., depth 3,146 meters, dynamic height 971.018 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.52	33.51	0	8.52	33.51	26.04
27	8.52	33.53	25	8.50	33.53	26.06
54	5.16	33.89	50	5.30	33.83	26.73
82	4.80	34.14	75	4.90	34.08	26.98
108	4.59	34.23	100	4.60	34.20	27.11
163	4.07	34.36	150	4.15	34.32	27.24
217	4.14	34.55	200	4.10	34.49	27.39
325	4.86	34.85	300	4.80	34.82	27.57
445	4.06	34.85	400	4.30	34.85	27.65
666	4.45	34.99	600	4.35	34.96	27.73
887	4.05	34.96	800	4.25	34.97	27.75
1,108	3.74	34.95	1,000	3.85	34.95	27.78
1,546	3.45	34.91				

Station 2712; June 2; latitude 42°04′ N., longitude 49°08′ W., depth 3155 meters, dynamic height 971.008 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	10.62	34.36	0	10.62	34.36	26.35
25	11.78	34.72	25	11.78	34.72	26.43
50	4.97	33.92	50	4.97	33.92	26.84
75	5.39	34.24	75	5.39	34.24	27.04
100	5.65	34.34	100	5.65	34.34	27.09
150	5.63	34.51	150	5.63	34.51	27.23
201	4.41	34.51	200	4.40	34.51	27.37
301	5.73	34.91	300	5.70	34.91	27.53
372	3.94	34.73	400	4.00	34.76	27.61
560	4.58	34.97	600	4.55	34.98	27.73
750	4.33	34.99	800	4.20	34.98	27.77
943	3.88	34.94	1000	3.80	34.94	27.78
1,334	3.60	34.94				

Station 2713; June 3; latitude 39°04′ N., longitude 50°31′ W., depth 5192 meters, dynamic height 971.672 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	20.60	36.35	0	20.60	36.35	25.64
27	------	36.34	25	20.55	36.34	25.65
53	19.93	36.32	50	20.10	36.32	25.76
81	19.04	36.37	75	19.25	36.35	26.00
107	18.44	36.45	100	18.55	36.44	26.26
161	17.82	36.43	150	17.95	36.44	26.40
214	17.58	36.43	200	17.60	36.43	26.48
321	16.44	36.20	300	16.80	36.26	26.54
429	14.17	35.79	400	14.75	35.90	26.73
529	12.27	35.47	600	10.85	35.28	27.04
694	8.95	------	800	6.95	35.00	27.45
852	6.12	34.98	1,000	5.00	34.98	27.68
1,221	4.32	34.98	1,500	4.05	34.97	27.77
1,660	3.96	34.96	2,000	3.60	34.94	27.80
2,112	3.48	34.93				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2714; June 3; latitude 39°47′ N., longitude 50°30′ W., depth 5121 meters, dynamic height 971.805 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	21.08	36.28	0	21.08	36.28	25.46
24	20.88	36.28	25	20.85	36.28	25.52
49	19.90	36.40	50	19.90	36.41	25.88
73	19.30	36.48	75	19.30	36.48	26.09
98	18.81	36.50	100	18.75	36.50	26.24
147	18.14	36.45	150	18.10	36.45	26.37
195	17.75	36.43	200	17.70	36.43	26.46
293	17.35	36.39	300	17.35	36.38	26.50
391	16.96	36.34	400	16.90	36.33	26.58
580	*13.84	35.81	600	13.55	35.76	26.88
760	10.62	35.48	800	9.65	35.37	27.31
931	6.63	35.02	1,000	5.85	35.00	27.59
1,352	4.26	34.99	1,500	4.00	34.98	27.79
1,843	3.72	34.94	2,000	3.65	34.94	27.79
2,356	3.44	34.94				

Station 2715; June 3; latitude 40°10′ N., longitude 50°29′ W., depth 4390 meters, dynamic height 971.883 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	19.57	36.43	0	19.57	36.43	25.99
23	19.17	36.42	25	19.15	36.42	26.08
45	19.05	36.41	50	19.05	36.41	26.10
68	19.00	36.42	75	19.00	36.42	26.12
91	19.00	36.43	100	18.90	36.44	26.16
136	18.48	36.47	150	18.35	36.47	26.33
182	18.14	36.47	200	18.05	36.47	26.40
272	17.83	36.44	300	17.80	36.44	26.44
363	17.72	36.44	400	17.50	36.42	26.50
707	12.25	35.45	600	14.40	35.83	26.76
947	7.18	35.03	800	10.25	35.21	27.08
1,187	4.95	35.01	1,000	6.45	35.02	27.52
1,797	3.56	34.91	1,500	3.90	34.96	27.78
2,403	3.46	34.92	2,000	3.50	34.91	27.78
3,012	3.16	34.93	2,500	3.40	34.92	27.80
			3,000	3.15	34.93	27.83

Station 2716; June 3; latitude 40°32′ N., longitude 50°26′ W., depth 3,621 meters, dynamic height 971.734 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	20.09	36.37	0	20.09	36.37	25.80
24	19.89	36.38	25	19.90	36.38	25.87
48	19.79	36.37	50	19.80	36.37	25.88
71	19.76	36.37	75	19.75	36.37	25.89
95	19.03	36.42	100	18.95	36.43	26.16
143	18.45	36.46	150	18.40	36.46	26.31
190	18.08	36.45	200	18.00	36.44	26.40
286	17.55	36.39	300	17.50	36.38	26.48
381	17.11	36.35	400	16.95	36.33	26.56
592	14.01	35.78	600	13.90	35.76	26.81
791	9.10	35.15	800	8.90	35.13	27.26
991	5.56	35.00	1,000	5.50	35.00	27.64
1,494	3.82	34.93	1,500	3.80	34.93	27.78
1,994	3.44	34.90	2,000	3.45	34.90	27.78
2,495	3.30	34.92	2,500	3.30	34.92	27.82

Station 2717; June 3–4; latitude 40°54° N., longitude 50°23′ W., depth 4,115 meters, dynamic height 971.710 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	21.40	36.34	0	21.40	36.34	25.42
21	21.37	36.35	25	21.35	36.36	25.46
41	-------	36.43	50	20.95	36.39	25.60
62	-------	36.36	75	20.20	36.37	25.77
82	19.97	36.38	100	19.55	36.34	25.92
124	19.08	36.29	150	18.70	36.42	26.21
165	18.50	36.46	200	18.10	36.45	26.38
248	17.63	36.39	300	16.70	36.22	26.55
330	16.15	36.11	400	15.00	35.94	26.72
485	13.39	35.72	600	10.35	35.28	27.13
650	9.11	35.16	800	6.50	35.02	27.53
818	6.32	35.01	1,000	5.00	34.98	27.69
1,246	4.09	34.96	1,500	3.75	34.94	27.79
1,690	3.58	34.92	2,000	3.40	(34.92)	27.78
2,151	3.37	-------				

Station 2718; June 4; latitude 41°19′ N., longitude 50°20′ W., depth 3,475 meters, dynamic height 971.321 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	20.94	36.29	0	20.94	36.29	25.51
23	19.86	36.26	25	19.80	36.25	25.78
46	18.55	36.22	50	18.25	36.20	26.15
69	17.05	35.99	75	17.05	36.01	26.29
91	17.11	36.12	100	16.70	36.06	26.42
136	14.54	35.67	150	14.35	35.68	26.66
182	14.04	35.74	200	13.85	35.71	26.79
273	12.11	35.40	300	10.40	35.16	27.03
364	9.24	35.11	400	8.70	35.10	27.26
328	9.18	34.97	600	5.45	34.95	27.60
427	8.21	35.08	800	4.20	34.91	27.72
521	6.59	34.98	1,000	3.95	34.91	27.74
734	4.33	34.92				
891	4.05	34.90				
1,004	3.92	34.91				

Station 2719; June 4; latitude 41°41′ N., longitude 50°13′ W., depth 3,658 meters, dynamic height 971.003 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.47	33.23	0	8.47	33.23	25.84
22	2.39	33.05	25	2.20	33.05	26.42
43	0.87	33.33	50	0.90	33.41	26.80
65	0.97	33.63	75	2.10	33.90	27.10
86	3.62	34.08	100	3.15	34.10	27.17
129	2.68	34.13	150	2.65	34.23	27.33
173	2.69	34.34	200	2.75	34.41	27.46
259	3.03	34.54	300	4.00	34.71	27.58
345	5.09	34.92	400	4.90	34.92	27.65
644	3.90	34.88	600	4.00	34.88	27.72
861	3.69	34.89	800	3.75	34.88	27.74
1,079	3.56	34.90	1,000	3.60	34.90	27.77
1,631	3.34	34.90	1,500	3.40	34.90	27.79
2,203	3.17	34.90	2,000	3.25	34.90	27.80
2,787	2.78	-------	2,500	2.95	(34.90)	27.83

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2720; June 4; latitude 42°06′ N., longitude 50°11′ W., depth 3,521 meters, dynamic height 971.011 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	9.57	33.46	0	9.57	33.46	25.84
25	6.84	33.73	25	6.84	33.73	26.47
50	7.52	34.50	50	7.52	34.50	26.97
76	8.00	34.70	75	8.00	34.70	27.06
101	6.04	34.48	100	6.25	34.49	27.15
151	4.09	34.31	150	4.10	34.31	27.25
202	6.36	34.82	200	6.35	34.82	27.39
302	5.16	34.85	300	5.20	34.85	27.55
403	4.61	34.87	400	4.65	34.87	27.64
586	4.36	34.95	600	4.35	34.95	27.73
782	4.10	34.95	800	4.05	34.95	27.76
978	3.84	34.94	1,000	3.85	34.94	27.78
1,468	3.55	34.93	1,500	3.55	34.93	27.80
1,964	3.28	34.92	2,000	3.25	34.92	27.82
2,463	3.04	34.91	2,500	3.05	34.91	27.83

Station 2721; June 4; latitude 42′45° N., longitude 50°06′ W., depth 1,463 meters, dynamic height 970.976 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	6.69	33.82	0	6.69	33.82	26.56
25	5.73	33.76	25	5.73	33.76	26.63
50	5.31	33.88	50	5.31	33.88	26.78
75	5.65	34.10	75	5.65	34.10	26.91
100	4.74	34.12	100	4.74	34.12	27.03
150	3.88	34.54	150	3.88	34.54	27.46
199	2.78	34.50	200	2.80	34.50	27.52
299	2.70	34.59	300	2.70	34.59	27.61
398	2.96	34.68	400	2.95	34.68	27.66
594	4.01	34.90	600	4.00	34.90	27.73
788	3.82	34.91	800	3.80	34.91	27.76
985	3.60	34.90	1,000	3.60	34.90	27.77
1,380	3.37	34.89				

Station 2722; June 4–5; latitude 42°49′ N., longitude, 50°05′ W., depth 622 meters, dynamic height 970.975 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	7.23	34.06	0	7.23	34.06	26.67
25	6.53	34.00	25	6.53	34.00	26.71
50	5.56	34.06	50	5.56	34.06	26.89
75	4.34	34.16	75	4.34	34.16	27.10
100	3.83	34.22	100	3.83	34.22	27.21
150	4.14	34.47	150	4.14	34.47	27.37
200	3.29	34.53	200	3.29	34.53	27.51
300	2.69	34.58	300	2.69	34.58	27.60
395	3.22	34.71	400	3.25	34.71	27.65
595	3.56	34.79	600	3.55	34.79	27.69

Station 2723; June 5; latitude 42°59′ N., longitude 50°04′ W., depth 162 meters, dynamic height 971.033 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	2.74	33.48	0	2.74	33.48	26.72
26	3.68	33.98	25	3.65	33.98	27.03
51	3.86	34.02	50	3.85	34.02	27.05
77	3.18	34.06	75	3.20	34.06	27.14
103	3.01	34.04	100	3.00	34.04	27.15
154	3.10	34.11	150	3.10	34.10	27.18

Station 2724; June 5; latitude 43°07′ N., longitude 50°07′ W., depth 88 meters, dynamic height 971.051 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	2.40	33.26	0	2.40	33.26	26.58
26	2.92	33.79	25	2.95	33.78	26.94
51	2.95	33.80	50	2.95	33.79	26.95
77	2.96	33.79	75	2.95	33.79	26.95

Station 2725; June 5; latitude 43°28′ N., longitude 50°05′ W., depth 60 meters, dynamic height 971.086 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	3.33	32.96	0	3.33	32.96	26.25
26	1.18	32.99	25	1.20	32.99	26.44
53	1.21	33.14	50	1.20	33.10	26.53

Station 2726; June 5; latitude 43°08′ N., longitude 50°37′ W., depth 88 meters, dynamic height 971.092 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	4.60	33.04	0	4.60	33.04	26.19
27	2.87	33.09	25	3.05	33.09	26.38
53	0.18	33.26	50	0.25	33.24	26.70
80	−0.03	33.32	75	0.00	33.31	26.76

Station 2727; June 5; latitude 42°55′ N., longitude 50°48′ W., depth 640 meters, dynamic height 971.088 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	3.89	32.96	0	3.89	32.96	26.20
25	1.41	33.02	25	1.41	33.02	26.46
51	0.32	33.14	50	0.35	33.13	26.60
76	−0.75	33.31	75	−0.75	33.31	26.79
101	−0.66	33.44	100	−0.65	33.43	26.90
152	0.44	33.82	150	0.40	33.79	27.14
203	1.34	34.06	200	1.30	34.05	27.28
304	1.71	34.20	300	1.70	34.19	27.37
402	2.42	34.42	400	2.40	34.41	27.49
601	3.56	34.72	600	3.55	34.72	27.63

Station 2728; June 5; latitude 42°49′ N., longitude 50°56′ W., depth 1,463 meters, dynamic height 971.087 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	4.53	32.97	0	4.53	32.97	26.14
25	0.93	33.06	25	0.93	33.06	26.52
51	−0.30	33.22	50	−0.25	33.21	26.70
76	−0.50	33.38	75	−0.50	33.37	26.84
101	−0.62	33.50	100	−0.60	33.49	26.94
152	0.45	33.82	150	0.40	33.80	27.14
203	0.78	33.97	200	0.75	33.96	27.25
304	1.65	34.17	300	1.60	34.16	27.35
405	2.58	34.49	400	2.50	34.47	27.53
598	3.44	34.74	600	3.45	34.74	27.66
786	4.11	34.88	800	4.10	34.88	27.71
982	3.75	34.89	1,000	3.70	34.89	27.76
1,376	3.45	34.88				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2729; June 5; latitude 42°26′ N., longitude 51°16′ W., depth 2,570 meters, dynamic height 971.169 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	13.13	34.52	0	13.13	34.52	26.01
25	14.65	35.48	25	14.65	35.48	26.44
50	12.75	35.30	50	12.75	35.30	26.70
75	12.44	35.33	75	12.44	35.33	26.78
100	13.02	35.55	100	13.02	35.55	26.84
150	10.79	35.08	150	10.79	35.08	26.90
199	10.74	35.16	200	10.75	35.16	26.97
299	9.11	35.12	300	9.10	35.12	27.22
376	6.67	34.85	400	6.40	34.87	27.42
560	5.22	34.96	600	4.95	34.95	27.68
743	4.01	34.88	800	4.00	34.89	27.73
934	4.07	34.94	1,000	4.00	34.94	27.77
1,320	3.58	34.91				

Station 2730; June 5; latitude 42°04′ N., longitude 51°53′ W., depth 3,457 meters, dynamic height 971.260 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	16.76	35.51	0	16.76	35.51	25.97
35	14.15	35.55	25	14.65	35.53	26.47
71	14.46	35.78	50	14.25	35.61	26.62
106	14.08	35.71	75	14.45	35.78	26.71
141	13.30	35.55	100	14.15	35.73	26.73
211	12.50	35.43	150	13.20	35.53	26.78
282	11.11	35.31	200	12.65	35.45	26.83
423	8.52	35.09	300	10.85	35.28	27.04
557	6.25	34.99	400	8.95	35.12	27.24
835	4.40	34.95	600	5.75	34.98	27.58
1,113	3.97	34.95	800	4.50	34.95	27.71
1,391	3.74	34.94	1,000	4.10	34.95	27.76
1,953	3.42	34.92				

Station 2731; June 6; latitude 42°00′ N., longitude 50°56′ W., depth 3,164 meters, dynamic height 971.236 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	19.80	36.21	0	19.80	36.21	25.75
35	16.27	35.63	25	17.00	35.77	26.12
71	15.24	35.87	50	15.80	35.74	26.38
106	14.20	35.75	75	15.15	35.86	26.62
141	13.57	35.65	100	14.35	35.77	26.72
212	11.72	35.34	150	13.40	35.62	26.80
284	10.77	35.34	200	12.00	35.37	26.89
425	7.49	35.04	300	10.45	35.32	27.13
570	5.53	34.98	400	8.10	35.09	27.35
851	4.17	34.92	600	5.30	34.97	27.63
1,130	3.97	34.95	800	4.25	34.93	27.72
1,410	3.55	34.92	1,000	4.05	34.94	27.75
1,969	3.38	34.89				

Station 2732; June 21; latitude 43°30′ N., longitude 50°13′ W., depth 59 meters, dynamic height 971.100 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	7.07	32.90	0	7.07	32.90	25.77
21	1.41	33.06	25	1.35	33.08	26.50
48	1.09	33.17	50	1.05	33.18	26.61

Station 2733; June 22; latitude 43°00′ N., longitude 50°09′ W., depth 88 meters, dynamic height 971.101 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	5.96	32.81	0	5.96	32.81	25.86
26	1.53	32.98	25	1.70	32.97	26.39
52	−0.26	33.19	50	−0.20	33.17	26.66
78	−0.33	33.29	75	−0.30	33.28	26.75

Station 2734; June 22; latitude 42°55′ N., longitude 50°08′ W., depth 165 meters, dynamic height 971.114 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	5.47	32.67	0	5.47	32.67	25.79
25	4.16	32.77	25	4.16	32.77	26.02
50	−0.67	33.10	50	−0.67	33.10	26.62
75	−0.51	33.24	75	−0.51	33.24	26.73
101	−1.18	33.24	100	−1.15	33.24	26.75
151	−0.68	33.38	150	−0.70	33.37	26.84

Station 2735; June 22; latitude 42°50′ N., longitude 50°08′ W., depth 631 meters, dynamic height 971.064 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	6.07	32.74	0	6.07	32.74	25.78
25	0.87	32.94	25	0.87	32.94	26.41
50	−0.91	33.29	50	−0.91	33.29	26.79
75	−1.08	33.34	75	−1.08	33.34	26.82
101	−1.17	33.39	100	−1.15	33.39	26.87
151	−0.48	33.57	150	−0.50	33.56	26.99
201	2.03	34.07	200	2.00	34.06	27.24
302	3.11	34.48	300	3.10	34.48	27.48
400	3.38	34.63	400	3.40	34.63	27.57
598	3.59	34.82	600	3.60	34.82	27.70

Station 2736; June 22; latitude 42°43′ N., longitude 50°08′ W., depth 1,463 meters, dynamic height 971.024 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	6.40	32.77	0	6.40	32.77	25.76
25	2.73	32.94	25	2.73	32.94	26.28
50	−0.83	33.16	50	−0.83	33.16	26.67
75	−1.59	33.36	75	−1.59	33.36	26.86
100	−1.40	33.47	100	−1.40	33.47	26.94
150	−0.02	33.81	150	−0.02	33.81	27.17
201	4.89	34.56	200	4.90	34.56	27.36
301	3.24	34.63	300	3.25	34.63	27.58
393	3.43	34.73	400	3.45	34.74	27.65
589	3.90	34.89	600	3.90	34.89	27.73
786	3.79	34.92	800	3.80	34.92	27.76
983	3.69	34.93	1,000	3.70	34.93	27.78
1,379	3.58	34.94				

Station 2737; June 22; latitude 42°20′ N., longitude 50°16′ W., depth 2,834 meters, dynamic height 970.970 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	9.24	33.35	0	9.24	33.35	25.80
25	8.34	33.74	25	8.34	33.74	26.25
50	5.30	33.82	50	5.30	33.82	26.72
75	3.84	33.96	75	3.84	33.96	26.99
100	1.38	34.00	100	1.38	34.00	27.24
150	2.23	34.33	150	2.23	34.33	27.43
201	3.19	34.52	200	3.15	34.52	27.50
301	3.92	34.77	300	3.90	34.75	27.62
402	4.48	34.92	400	4.45	34.92	27.69
600	4.23	34.98	600	4.25	34.98	27.76
795	4.04	34.99	800	4.05	34.99	27.79
995	3.81	34.97	1,000	3.80	34.97	27.80
1,396	3.49	34,94				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2738; June 22; latitude 42°05′ N., longitude 50°20′ W., depth 3,466 meters, dynamic height 971.015 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.85	32.88	0	7.85	32.88	25.65
25	1.80	33.05	25	1.80	33.05	26.45
50	1.43	33.47	50	1.43	33.47	26.80
75	5.32	34.13	75	5.32	34.13	26.96
101	3.94	34.13	100	4.00	34.13	27.11
151	2.24	33.96	150	2.25	33.96	27.14
201	1.99	34.23	200	2.00	34.22	27.36
302	3.33	34.57	300	3.35	34.56	27.52
388	3.66	34.74	400	3.70	34.76	27.65
581	4.21	34.94	600	4.20	34.94	27.74
772	4.03	34.96	800	4.00	34.95	27.77
965	3.66	34.93	1,000	3.60	34.93	27.79
1,353	3.45	34.94				

Station 2739; June 22; latitude 41°28′ N., longitude 50°14′ W., depth 3,521 meters, dynamic height 971.159 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	16.33	34.72	0	16.33	34.72	25.47
25	14.62	35.10	25	14.62	35.10	26.16
50	12.00	34.92	50	12.00	34.92	26.55
75	12.14	35.20	75	12.14	35.20	26.74
100	12.44	35.37	100	12.44	35.37	26.81
150	12.40	35.48	150	12.40	35.48	26.91
200	10.72	35.26	200	10.72	35.26	27.05
300	7.90	34.98	300	7.90	34.98	27.30
398	4.00	34.51	400	4.00	34.51	27.42
583	3.44	34.77	600	3.45	34.78	27.69
760	3.76	34.86	800	3.80	34.88	27.74
963	3.89	34.95	1,000	3.90	34.95	27.78
1,383	3.78	34.98				

Station 2740; June 22; latitude 40°53′ N., longitude 50°08′ W., depth 3,429 meters, dynamic height 971.254 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	15.49	33.87	0	15.49	33.87	25.02
25	16.37	35.57	25	16.37	35.57	26.11
50	14.36	35.45	50	14.36	35.45	26.48
75	13.99	35.62	75	13.99	35.62	26.69
100	13.36	35.53	100	13.36	35.53	26.76
150	13.31	35.62	150	13.31	35.62	26.83
199	12.23	35.45	200	13.20	35.45	26.92
299	10.62	35.30	300	10.60	35.30	27.10
395	8.65	35.12	400	8.55	35.11	27.30
590	3.42	34.62	600	3.45	34.63	27.57
783	4.67	34.99	800	4.65	34.99	27.73
981	4.14	34.98	1,000	4.10	34.98	27.79
1,377	3.59	34.96				

Station 2741; June 23; latitude 41°30′ N., longitude 49°24′ W., depth 2,661 meters, dynamic height 970.983 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	11.47	33.42	0	11.47	33.42	25.49
25	11.72	35.28	25	11.72	35.28	26.89
50	11.43	35.27	50	11.43	35.27	26.93
76	10.18	35.08	75	10.20	35.08	27.00
101	10.95	35.38	100	10.95	35.38	27.11
151	8.57	35.10	150	8.60	35.10	27.28
202	7.86	35.09	200	7.90	35.09	27.38
303	5.61	34.94	300	5.75	34.95	27.57
402	3.84	34.83	400	3.85	34.83	27.69
600	5.19	35.13	600	5.20	35.13	27.78
797	4.09	35.00	800	4.10	35.00	27.80
996	3.86	34.99	1,000	3.85	34.99	27.81
1,395	3.45	34.95				

Station 2742; June 23; latitude 41°09′ N., longitude 48°34′ W., depth 2,780 meters, dynamic height 970.946 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	13.64	33.38	0	13.64	33.38	25.03
25	3.61	33.60	25	3.61	33.60	26.74
50	3.80	34.05	50	3.80	34.05	27.07
75	3.04	34.18	75	3.04	34.18	27.25
100	4.32	34.44	100	4.32	34.42	27.32
150	3.98	34.53	150	3.98	34.53	27.44
200	4.07	34.66	200	4.07	34.66	27.53
300	4.39	34.86	300	4.39	34.86	27.65
394	5.05	35.02	400	5.05	35.02	27.71
592	4.30	34.98	600	4.30	34.98	27.76
789	4.05	35.00	800	4.05	35.00	27.80
987	3.86	34.99	1,000	3.85	34.99	27.81
1,385	3.48	34.97				

Station 2743; June 23; latitude 41°22′ N., longitude 47°17′ W., depth 4,006 meters, dynamic height 971.292 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	18.94	35.22	0	18.94	35.22	25.22
24	18.01	35.88	25	18.00	35.88	25.97
49	15.38	35.62	50	15.35	35.62	26.39
73	14.39	35.63	75	14.40	35.63	26.61
97	14.36	35.76	100	14.30	35.76	26.73
146	13.84	35.72	150	13.75	35.71	26.81
195	12.97	35.58	200	12.90	35.57	26.88
292	11.60	35.42	300	11.40	35.40	27.04
302	11.28	35.38	400	8.85	35.16	27.29
449	7.99	35.11	600	6.40	35.04	27.55
594	6.41	35.05	800	4.80	34.99	27.71
757	4.99	34.99	1,000	4.35	35.00	27.77
1,103	4.17	35.01				

Station 2744; June 24; latitude 41°44′ N., longitude 47°51′ W., depth 3,676 meters, dynamic height 971.197 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	17.72	34.74	0	17.72	34.74	25.16
25	16.09	35.68	25	16.09	35.68	26.27
49	14.88	35.78	50	14.85	35.78	26.63
74	14.30	35.76	75	14.30	35.76	26.73
98	13.80	35.70	100	13.70	35.69	26.80
147	12.74	35.54	150	12.70	35.54	26.89
197	11.78	35.42	200	11.70	35.41	26.99
295	10.08	35.30	300	10.05	35.29	27.19
392	8.34	35.15	400	8.25	35.14	27.37
587	5.12	34.96	600	5.10	34.96	27.65
781	4.75	35.05	800	4.70	35.05	27.77
977	4.25	35.01	1,000	4.20	35.02	27.81
1,370	3.67	34.97				

Station 2745; June 24; latitude 42°06′ N., longitude 48°26′ W., depth 3,329 meters, dynamic height 971.135 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	14.54	33.59	0	14.54	33.59	25.00
25	13.91	35.24	25	13.91	35.24	26.42
50	13.84	35.65	50	13.84	35.65	26.74
75	13.25	35.59	75	13.25	35.59	26.82
100	12.83	35.54	100	12.83	35.54	26.87
150	11.40	35.31	150	11.40	35.31	26.97
201	11.11	35.38	200	11.10	35.38	27.08
301	8.78	35.16	300	8.85	35.16	27.29
381	5.54	34.76	400	5.45	34.76	27.45
571	5.08	35.00	600	5.00	35.01	27.71
762	4.45	35.02	800	4.35	35.02	27.79
956	3.99	34.99	1,000	3.90	34.98	27.81
1,350	3.48	34.94				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2746; June 24; latitude 42°36′ N., longitude 49°12′ W., depth 2,488 meters, dynamic height 970.980 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.06	34.15	0	13.06	34.15	25.74
23	7.38	33.75	25	7.10	33.74	26.44
46	5.17	33.57	50	5.40	33.71	26.63
69	6.66	34.51	75	6.80	34.57	27.13
92	7.18	34.67	100	7.30	34.71	27.17
138	8.04	35.00	150	8.05	35.04	27.32
185	7.88	35.07	200	7.45	35.05	27.41
277	5.08	34.83	300	5.25	34.91	27.60
323	5.37	34.97	400	4.85	34.96	27.68
492	4.20	34.94	600	4.20	34.98	27.78
665	4.21	35.00	800	3.75	34.97	27.81
847	3.67	34.95	1,000	3.55	34.96	27.82
1,229	3.49	34.95				

Station 2747; June 24; latitude 43°20′ N., longitude 49°05′ W., depth 1,463 meters, dynamic height 970.954 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.69	32.80	0	7.69	32.80	25.62
25	2.42	33.09	25	2.42	33.09	26.43
50	−0.48	33.32	50	−0.48	33.32	26.79
76	−0.82	33.62	75	−0.80	33.62	27.05
101	−0.46	33.77	100	−0.50	33.76	27.15
151	0.97	34.20	150	0.95	34.19	27.41
202	1.98	34.42	200	1.90	34.41	27.53
303	2.90	34.68	300	2.85	34.67	27.66
402	3.82	34.86	400	3.80	34.85	27.71
601	4.11	34.98	600	4.10	34.97	27.78
800	3.71	34.94	800	3.70	34.94	27.79
1,000	3.51	34.94	1,000	3.50	34.94	27.81
1,400	3.38	34.93				

Station 2748; June 24–25; latitude 43°02′ N., longitude 48°15′ W., depth 2,972 meters, dynamic height 970.971 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	10.93	33.72	0	10.93	33.72	25.82
25	6.23	33.73	25	6.23	33.73	26.55
50	8.45	34.65	50	8.45	34.65	26.95
75	7.22	34.53	75	7.22	34.53	27.04
100	8.37	34.83	100	8.37	34.83	27.11
150	4.43	34.36	150	4.43	34.36	27.25
199	3.97	34.52	200	3.95	34.53	27.44
299	4.43	34.82	300	4.45	34.82	27.62
358	4.48	34.90	400	4.45	34.93	27.71
538	4.15	34.96	600	4.00	34.96	27.78
718	3.83	34.95	800	3.75	34.95	27.79
906	3.66	34.95	1,000	3.60	34.94	27.80
1,289	3.38	34.92				

Station 2749; June 25; latitude 42°46′ N., longitude 47°29′ W., depth 3,603 meters, dynamic height 971.006 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.15	33.53	0	13.15	33.53	25.24
24	11.53	34.54	25	11.50	34.56	26.36
48	10.57	35.02	50	10.40	35.01	26.91
72	8.31	34.68	75	8.30	34.68	27.00
96	7.90	34.73	100	7.80	34.73	27.12
144	5.81	34.52	150	5.70	34.52	27.24
193	5.14	34.56	200	5.05	34.57	27.35
289	4.00	34.68	300	4.05	34.70	27.56
351	4.25	34.82	400	4.45	34.90	27.68
527	4.63	34.99	600	4.45	34.99	27.75
704	4.11	34.98	800	4.00	34.98	27.80
891	3.92	34.98	1,000	3.75	34.97	27.81
1,277	3.46	34.94				

Station 2750; June 25; latitude 42°30′ N., longitude 46°39′ W., depth 4,161 meters, dynamic height 971.327 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	18.11	35.04	0	18.11	35.04	25.30
22	19.27	35.96	25	19.20	35.95	25.71
44	16.54	35.82	50	16.25	35.79	26.32
65	15.68	35.76	75	15.40	35.80	26.52
87	15.09	35.84	100	14.85	35.84	26.67
131	14.44	35.84	150	14.15	35.78	26.78
175	13.67	35.70	200	13.15	35.61	26.85
262	11.87	35.41	300	11.55	35.47	27.06
240	12.30	35.55	400	9.30	35.13	27.20
355	11.03	35.47	600	5.65	34.80	27.46
468	5.87	34.58	800	4.60	34.98	27.73
584	5.67	34.78	(1,000)	4.10	34.96	27.77
814	4.53	34.98				

Station 2751; June 25; latitude 42°18′ N., longitude 46°02′ W., depth 4,436 meters, dynamic height 971.594 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	20.98	36.22	0	20.98	36.22	25.45
24	18.76	36.20	25	18.70	36.20	26.03
49	17.90	36.35	50	17.90	36.35	26.35
73	17.84	36.37	75	17.85	36.37	26.38
97	17.47	36.35	100	17.40	36.35	26.48
146	17.00	36.34	150	17.00	36.34	26.56
194	16.84	36.34	200	16.80	36.34	26.61
291	15.95	36.17	300	15.80	36.15	26.70
469	12.85	35.60	400	14.10	35.83	26.82
696	8.63	35.14	600	10.40	35.27	27.11
917	5.52	35.03	800	6.95	35.07	27.51
1,159	4.51	35.01	1,000	5.05	35.02	27.71
1,663	3.67	34.97				

Station 2752; June 25; latitude 42°51′ N., longitude 45°52′ W., depth 4,463 meters, dynamic height 971.323 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	18.71	35.31	0	18.71	35.31	25.35
24	19.84	36.11	25	19.80	36.11	25.68
49	17.27	36.07	50	17.20	36.07	26.31
73	15.56	35.83	75	15.55	35.83	26.51
97	15.09	35.83	100	15.00	35.83	26.63
146	14.11	35.73	150	14.10	35.73	26.75
194	13.69	35.71	200	13.60	35.70	26.83
291	11.89	35.41	300	11.75	35.39	26.96
332	11.14	35.32	400	9.55	35 20	27.20
487	7.36	35.05	600	5.55	34.88	27.53
635	5.26	34.85	800	4.55	34.97	27.73
755	4.77	34.98	(1,000)	3.70	34.95	27.80
949	3.84	34.95				

Station 2753; June 25; latitude 43°24′ N., longitude 45°44′ W., depth 4317 meters, dynamic height 971.185 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	16.61	34.61	0	16.61	34.61	25.32
27	15.37	35.87	25	15.40	35.79	26.50
54	14.33	35.72	50	14.45	35.74	26.68
82	13.58	35.63	75	13.80	35.65	26.75
108	12.97	35.55	100	13.10	35.57	26.83
163	12.08	35.42	150	12.25	35.44	26.90
217	11.49	35.39	200	11.70	35.40	26.98
325	6.89	34.58	300	7.60	34.73	27.14
486	5.71	34.96	400	6.20	34.77	27.37
735	4.65	35.01	600	5.20	35.00	27.67
988	3.99	34.98	800	4.45	35.00	27.76
1,249	3.77	34.97	1,000	3.95	34.98	27.79
1,790	3.39	34.93				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2754; June 26; latitude 43°44′ N., longitude 46°42′ W., depth 4,216 meters, dynamic height 971.003 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	13.46	33.83	0	13.46	33.83	25.42
23	8.91	34.20	25	8.80	34.23	26.56
46	8.03	34.63	50	8.10	34.69	27.03
68	8.38	34.81	75	8.10	34.80	27.12
91	7.73	34.78	100	7.70	34.79	27.17
137	7.55	34.89	150	6.65	34.76	27.30
183	4.36	34.53	200	3.65	34.48	27.42
274	2.25	34.41	300	2.25	34.44	27.52
336	2.37	34.49	400	2.90	34.60	27.61
515	3.72	34.80	600	4.10	34.90	27.72
702	4.24	34.96	800	4.05	34.96	27.77
890	3.87	34.95	1,000	3.70	34.94	27.79
1,278	3.45	34.93				

Station 2755; June 26; latitude 44°05′ N., longitude 47° 43′ W., depth 3,585 meters, dynamic height 970.972 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	11.27	33.70	0	11.27	33.70	25.73
25	8.23	34.11	25	8.23	34.11	26.56
49	6.79	34.27	50	6.70	34.27	26.91
74	4.97	34.23	75	5.00	34.28	27.08
99	5.89	34.53	100	5.90	34.55	27.23
148	5.97	34.72	150	5.95	34.72	27.36
197	4.76	34.69	200	4.75	34.69	27.48
296	5.38	34.93	300	5.40	34.93	27.59
364	4.58	34.88	400	4.50	34.90	27.67
547	4.28	34.96	600	4.15	34.96	27.76
732	3.86	34.96	800	3.80	34.95	27.79
916	3.70	34.94	1,000	3.65	34.94	27.79
1,286	3.39	34.93				

Station 2756; June 26; latitude 44°18′ N., longitude 48°36′ W., depth 2,743 meters, dynamic height 970.908 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	8.37	33.13	0	8.37	33.13	25.77
24	6.23	33.67	25	6.20	33.68	26.50
48	3.96	33.81	50	3.80	33.84	26.90
73	2.56	34.19	75	2.55	34.22	27.33
97	3.78	34.51	100	3.70	34.51	27.45
145	2.81	34.54	150	2.75	34.55	27.57
193	2.68	34.63	200	2.75	34.64	27.64
290	4.11	34.90	300	4.15	34.90	27.71
370	4.00	34.91	400	3.95	34.91	27.74
558	3.80	34.93	600	3.75	34.93	27.77
748	3.61	34.93	800	3.55	34.93	27.79
939	3.48	34.93	1,000	3.45	34.93	27.80
1,325	3.31	34.88				

Station 2757; June 26; latitude 44°20′ N., longitude 48°52′ W., depth 1,454 meters, dynamic height 970.955 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	7.41	32.75	0	7.41	32.75	25.61
25	3.04	33.03	25	3.04	33.03	26.33
50	0.45	33.25	50	0.45	33.25	26.70
75	0.35	33.69	75	0.35	33.69	27.05
99	0.26	33.90	100	0.25	33.91	27.24
149	1.17	34.21	150	1.20	34.22	27.43
199	3.40	34.62	200	3.45	34.63	27.56
298	3.81	34.81	300	3.80	34.81	27.68
389	3.49	34.81	400	3.50	34.81	27.71
585	3.58	34.89	600	3.55	34.89	27.76
782	3.54	34.91	800	3.55	34.91	27.78
980	3.48	34.91	1,000	3.50	34.91	27.79
1,376	3.40	34.91				

Station 2758; June 26; latitude 44°20′ N., longitude 49°02′ W., depth 320 meters, dynamic height 971.025 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.69	32.61	0	6.69	32.61	25.60
24	3.56	32.87	25	3.50	32.89	26.18
48	−1.31	33.25	50	−1.40	33.27	26.78
72	−1.60	33.34	75	−1.60	33.35	26.85
96	−1.48	33.45	100	−1.35	33.47	26.95
144	−0.07	33.81	150	0.05	33.85	27.20
193	0.66	34.07	200	0.70	34.09	27.35
289	1.47	34.31	(300)	1.55	34.33	27.48

Station 2759; June 26; latitude 44°21′ N., longitude 49°09′ W., depth 88 meters, dynamic height 971.064 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.17	32.62	0	8.17	32.62	25.40
26	1.76	32.83	25	2.00	32.82	26.25
51	−0.73	33.09	50	−0.65	33.08	26.61
77	−1.03	33.13	75	−1.00	33.12	26.65

Station 2760; June 27; latitude 44°23′ N., longitude 49°31′ W.; depth 50 meters, dynamic height 971.061 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	9.36	32.74	0	9.36	32.74	25.31
22	0.36	33.04	25	0.30	33.04	26.54
44	0.17	33.03	(50)	0.15	33.04	26.54

Station 2761; June 27; latitude 44°58′ N., longitude 49°37′ W.; depth 73 meters, dynamic height 971.083 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.89	32.63	0	8.89	32.63	25.30
26	1.97	32.74	25	2.30	32.73	26.16
52	−0.38	33.03	50	−0.20	32.99	26.52
			(75)	−0.80	33.27	26.76

Station 2762; June 27; latitude 44°54′ N., longitude 49°16′ W., depth 183 meters, dynamic height 971.083 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.52	32.62	0	7.52	32.62	25.49
25	1.14	32.81	25	1.14	32.81	26.30
49	−0.19	32.95	50	−0.20	32.95	26.48
74	−0.98	33.05	75	−1.00	33.05	26.59
99	−1.26	33.15	100	−1.25	33.15	26.68
148	−1.29	33.31	150	−1.30	33.32	26.82

Station 2763; June 27; latitude 44°53′ N., longitude 49°10′ W., depth 640 meters, dynamic height 971.084 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.92	32.61	0	7.92	32.61	25.43
25	0.65	32.83	25	0.65	32.83	26.34
50	−1.25	33.08	50	−1.25	33.08	26.62
75	−1.38	33.16	75	−1.38	33.16	26.69
99	−1.45	33.20	100	−1.45	33.20	26.72
149	−1.27	33.33	150	−1.25	33.33	26.82
199	−0.66	33.57	200	−0.65	33.58	27.01
298	1.54	34.29	300	1.65	34.30	27.46
388	3.03	34.69	400	3.15	34.71	27.66
584	3.42	34.82	600	3.45	34.83	27.72

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2764; June 27; latitude 44°51′ N., longitude 48°58′ W., depth 1,481 meters, dynamic height 971.029 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	6.66	32.64	0	6.66	32.64	25.63
25	0.53	33.04	25	0.53	33.04	26.52
51	−1.62	33.31	50	−1.60	33.30	26.81
76	−1.64	33.40	75	−1.65	33.40	26.90
101	−0.56	33.66	100	−0.60	33.65	27.06
152	−0.12	33.79	150	−0.15	33.78	27.15
203	0.32	33.91	200	0.30	33.90	27.22
304	1.13	34.23	300	1.10	34.21	27.43
386	2.28	34.53	400	2.45	34.57	27.61
572	3.63	34.88	600	3.60	34.89	27.76
755	3.53	34.90	800	3.55	34.90	27.77
945	3.51	34.91	1,000	3.50	34.91	27.79
1,327	3.50	34.90				

Station 2765; June 27; latitude 44°48′ N., longitude 48°37′ W., depth 2,232 meters, dynamic height 970.900 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	7.20	33.03	0	7.20	33.03	25.86
25	0.47	33.50	25	0.47	33.50	26.89
50	2.92	34.15	50	2.92	34.15	27.23
75	4.37	34.50	75	4.37	34.50	27.37
100	3.35	34.51	100	3.35	34.51	27.48
150	4.12	34.71	150	4.12	34.71	27.57
199	4.39	34.83	200	4.40	34.83	27.62
299	4.09	34.87	300	4.10	34.87	27.70
389	4.21	34.94	400	4.20	34.94	27.74
584	3.85	34.93	600	3.85	34.93	27.76
779	3.63	34.93	800	3.60	34.93	27.79
977	3.46	34.93	1,000	3.45	34.93	27.80
1,375	3.34	34.925				

Station 2766; June 27; latitude 44°43′ N., longitude 48°02′ W., depth 3,182 meters, dynamic height 970.889 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	9.49	33.59	0	9.49	33.59	25.95
25	3.53	33.81	25	3.53	33.81	26.90
51	1.76	34.05	50	1.85	34.03	27.22
76	1.35	34.21	75	1.35	34.20	27.40
101	1.71	34.33	100	1.65	34.32	27.48
152	2.94	34.58	150	2.85	34.57	27.58
203	4.10	34.79	200	4.05	34.78	27.62
304	3.64	34.81	300	3.65	34.81	27.69
403	3.79	34.88	400	3.80	34.88	27.73
604	3.75	34.92	600	3.75	34.92	27.77
804	3.69	34.95	800	3.70	34.95	27.80
1,003	3.50	34.92	1,000	3.50	34.92	27.80
1,397	3.32	34.92				

Station 2767; June 28; latitude 44°34′ N., longitude 46°56′ W., depth 3,658 meters, dynamic height 970.958 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	8.57	33.16	0	8.57	33.16	25.76
24	6.99	33.90	25	6.95	33.92	26.60
48	6.63	34.40	50	6.70	34.43	27.03
71	7.31	34.65	75	7.30	34.65	27.12
95	6.61	34.66	100	6.50	34.66	27.24
143	6.03	34.70	150	6.10	34.72	27.34
190	6.50	34.90	200	6.30	34.89	27.45
285	3.68	34.75	300	3.40	34.73	27.65
343	2.93	34.68	400	3.35	34.75	27.67
516	3.88	34.90	600	3.85	34.92	27.76
690	3.71	34.93	800	3.55	34.92	27.79
873	3.46	34.91	1,000	3.40	34.91	27.80
1,254	3.34	34.91				

Station 2768; June 28; latitude 44°26′ N., longitude 45°49′ W., depth 3,978 meters, dynamic height 971.103 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.50	33.58	0	13.50	33.58	25.21
22	10.65	34.38	25	10.70	34.47	26.44
45	12.56	-----	50	12.35	35.15	26.66
67	11.50	35.16	75	11.10	35.11	26.87
90	10.74	35.05	100	10.70	35.06	26.90
135	10.50	35.09	150	10.20	35.07	26.99
179	9.48	35.01	200	8.85	34.97	27.14
269	6.76	34.81	300	5.15	34.64	27.39
288	5.43	34.64	400	4.05	34.68	27.55
427	4.00	34.70	600	4.15	34.88	27.69
564	4.18	34.85	800	3.90	34.92	27.76
717	3.99	34.925	1,000	3.65	34.92	27.78
1,038	3.61	34.92				

Station 2769; June 28; latitude 45°01′ N., longitude 45°44′ W., depth 3,722 meters, dynamic height 971.000 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	9.60	33.37	0	9.60	33.37	25.76
25	8.50	33.92	25	8.50	33.92	26.37
49	7.01	34.15	50	7.00	34.16	26.78
74	6.16	34.30	75	6.10	34.30	27.01
98	4.49	34.22	100	4.45	34.23	27.14
147	4.28	34.35	150	4.15	34.35	27.27
196	2.62	34.35	200	2.65	34.36	27.43
294	5.32	34.91	300	5.40	34.93	27.59
362	5.47	35.01	400	5.40	35.01	27.66
544	4.62	34.99	600	4.50	34.99	27.74
726	4.22	34.99	800	4.10	34.98	27.78
914	3.84	34.96	1,000	3.70	34.95	27.80
1,298	3.34	34.915				

Station 2770; June 28; latitude 45°31′ N., longitude 45°39′ W., depth 3,603 meters, dynamic height 970.995 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	13.47	34.29	0	13.47	34.29	25.81
25	7.93	34.01	25	7.93	34.01	26.53
51	10.93	35.17	50	10.90	35.17	26.95
76	9.37	34.91	75	9.40	34.91	27.00
102	8.68	34.89	100	8.75	34.90	27.10
153	6.02	34.58	150	6.20	34.58	27.21
203	5.61	34.69	200	5.60	34.68	27.37
305	5.89	34.97	300	5.90	34.97	27.57
385	5.05	34.97	400	4.95	34.97	27.68
579	4.24	34.96	600	4.20	34.96	27.76
774	3.89	34.95	800	5.85	34.95	27.78
970	3.58	34.94	1,000	3.55	34.94	27.80
1,364	3.35	34.93				

Station 2771; June 28; latitude 45°32′ N., longitude 46°31′ W., depth 3,228 meters, dynamic height 970.904 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	10.20	33.72	0	10.20	33.72	25.95
24	7.44	34.08	25	7.40	34.09	26.67
49	5.18	34.28	50	5.15	34.30	27.12
73	4.84	34.45	75	4.85	34.46	27.29
98	4.67	34.55	100	4.65	34.56	27.39
147	4.30	34.69	150	4.30	34.70	27.54
195	4.22	34.81	200	4.25	34.82	27.64
293	4.44	34.92	300	4.45	34.92	27.70
387	4.21	34.95	400	4.20	34.95	27.75
580	3.84	34.93	600	3.80	34.93	27.77
772	3.55	34.92	800	3.55	34.92	27.79
968	3.52	34.93	1,000	3.55	34.93	27.79
1,363	3.29	34.93				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
Station 2772; June 29; latitude 45°33′ N., longitude 47°25′ W., depth 1,829 meters, dynamic height 970.897 meters						
0	7.71	33.09	0	7.71	33.09	25.84
25	5.73	34.12	25	5.73	34.12	26.91
50	6.17	34.55	50	6.17	34.55	27.19
75	5.71	34.64	75	5.71	34.64	27.32
100	5.34	34.71	100	5.34	34.71	27.43
150	5.23	34.81	150	5.23	34.81	27.52
200	3.65	34.68	200	3.65	34.68	27.58
300	3.68	34.85	300	3.68	34.85	27.72
402	3.85	34.89	400	3.85	34.89	27.73
602	3.71	34.92	600	3.70	34.92	27.78
801	3.54	34.92	800	3.55	34.92	27.79
1,000	3.42	34.91	1,000	3.40	34.91	27.80
1,398	3.30	34.91				
Station 2773; June 29; latitude 45°37′ N., longitude 47°32′ W., depth 1,463 meters, dynamic height 970.900 meters						
0	7.15	32.83	0	7.15	32.83	25.72
25	4.89	33.30	25	4.89	33.30	26.36
50	0.24	33.85	50	0.24	33.85	27.19
75	4.68	34.56	75	4.68	34.56	27.38
101	2.01	34.37	100	2.05	34.37	27.49
151	2.15	34.47	150	2.15	34.47	27.56
201	2.60	34.57	200	2.60	34.57	27.60
302	4.24	34.91	300	4.25	34.91	27.71
394	4.05	34.93	400	4.05	34.93	27.74
592	3.65	34.92	600	3.65	34.92	27.78
790	3.46	34.92	800	3.45	34.92	27.80
989	3.40	34.92	1,000	3.40	34.92	27.81
1,386	3.34	34.92				
Station 2774; June 29; latitude 45°45′ N., longitude 47°46′ W., depth 1,097 meters, dynamic height 970.949 meters						
0	6.64	32.81	0	6.64	32.81	25.77
25	4.17	32.98	25	4.17	32.98	26.18
51	−1.32	33.38	50	−1.30	33.35	26.84
76	−0.20	33.81	75	−0.25	33.80	27.17
101	0.56	34.06	100	0.50	34.05	27.33
152	1.22	34.26	150	1.20	34.25	27.45
203	2.07	34.47	200	2.00	34.45	27.55
304	3.01	34.70	300	3.00	34.69	27.66
391	3.62	34.85	400	3.60	34.85	27.73
582	3.54	34.88	600	3.55	34.88	27.75
770	3.57	34.90	800	3.55	34.90	27.77
980	3.47	34.90	1,000	3.45	34.90	27.78
Station 2775; June 29; latitude 45°47′ N., longitude 47°51′ W., depth 622 meters, dynamic height 970.994 meters						
0	6.56	32.89	0	6.56	32.89	25.84
25	4.47	32.92	25	4.47	32.92	26.10
50	−1.44	33.27	50	−1.44	33.27	26.78
75	−1.56	33.41	75	−1.56	33.41	26.90
100	−1.26	33.54	100	−1.26	33.54	27.00
150	0.28	33.97	150	0.28	33.97	27.28
201	1.23	34.27	200	1.25	34.26	27.46
301	2.57	34.59	300	2.55	34.58	27.61
397	3.47	34.81	400	3.50	34.81	27.71
598	3.56	34.86	600	3.55	34.86	27.74
Station 2776; June 29; latitude 45°52′ N., longitude 48°00′ W., depth 165 meters, dynamic height 971.042 meters						
0	6.38	32.60	0	6.38	32.60	25.64
25	0.78	32.79	25	0.78	32.79	26.31
51	−1.15	33.10	50	−1.05	33.09	26.63
76	−1.62	33.25	75	−1.60	33.25	26.77
102	−1.52	33.39	100	−1.55	33.38	26.88
159	−1.19	33.48	150	−1.20	33.47	26.95
Station 2777; June 29; latitude 45°56′ N., longitude 48°07′ W., depth 110 meters, dynamic height 971.047 meters						
0	6.81	32.56	0	6.81	32.56	25.54
26	1.32	32.86	25	1.50	32.86	26.32
52	−0.40	33.07	50	−0.15	33.05	26.57
78	−1.53	33.24	75	−1.55	33.23	26.75
104	−1.52	33.34	100	−1.50	33.32	26.83
Station 2778; June 29; latitude 46°10′ N., longitude 48°32′ W., depth 88 meters, dynamic height 971.063 meters						
0	7.48	32.61	0	7.48	32.61	25.49
26	2.11	32.64	25	2.25	32.64	26.09
53	−0.26	32.83	50	−0.15	32.80	26.36
79	−0.92	33.14	75	−0.85	33.10	26.62
Station 2779; June 29; latitude 46°09′ N., longitude 48°04′ W., depth 110 meters, dynamic height 971.063 meters						
0	7.31	32.56	0	7.31	32.56	25.48
26	2.18	32.66	25	2.25	32.66	26.11
52	−0.20	32.83	50	0.00	32.80	26.36
78	−1.37	33.11	75	−1.35	33.09	26.64
104	−1.23	33.29	100	−1.25	33.27	26.78
Station 2780; June 29; latitude 46°08′ N., longitude 47°45′ W., depth 165 meters, dynamic height 971.045 meters						
0	6.73	32.63	0	6.73	32.63	25.61
26	0.84	32.91	25	1.00	32.90	26.38
52	−1.49	33.15	50	−1.30	33.13	26.66
77	−1.67	33.22	75	−1.65	33.22	26.75
103	−1.66	33.29	100	−1.65	33.28	26.79
155	−1.42	33.41	150	−1.45	33.40	26.88
Station 2781; June 29; latitude 46°08′ N., longitude 47°21′ W., depth 622 meters, dynamic height 970.953 meters						
0	6.46	32.94	0	6.46	32.94	25.88
25	1.63	33.03	25	1.63	33.03	26.44
51	−1.27	33.39	50	−1.25	33.38	26.87
76	−0.72	33.68	75	−0.75	33.67	27.09
101	0.09	33.85	100	0.00	33.84	27.19
152	0.77	34.14	150	0.70	34.13	27.38
203	1.60	34.36	200	1.55	34.35	27.50
304	2.92	34.65	300	2.90	34.64	27.63
396	*3.38	34.79	400	3.40	34.79	27.70
596	3.48	34.89	600	3.50	34.89	27.77

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2782; June 29-30; latitude 46°07′ N., longitude 47°03′ W., depth 1,371 meters, dynamic height 970.888 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	7.53	33.17	0	7.53	33.17	25.92
25	3.75	33.59	25	3.75	33.59	26.71
50	2.54	34.07	50	2.54	34.07	27.21
75	2.57	34.31	75	2.57	34.31	27.39
101	2.54	34.44	100	2.55	34.43	27.49
151	2.55	34.58	150	2.55	34.58	27.61
201	3.09	34.72	200	3.05	34.72	27.68
302	3.49	34.80	300	3.50	34.80	27.70
396	3.67	34.88	400	3.65	34.88	27.74
594	3.60	34.89	600	3.60	34.89	27.76
793	3.45	34.91	800	3.45	34.91	27.79
989	3.42	34.91	1,000	3.45	34.91	27.79

Station 2783; June 30; latitude 46°06′ N., longitude 46°43′ W., depth 978 meters, dynamic height 970.885 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	7.00	33.04	0	7.00	33.04	25.90
25	5.84	34.07	25	5.84	34.07	26.86
50	0.94	33.96	50	0.94	33.96	27.23
74	1.90	34.23	75	1.90	34.24	27.39
99	1.84	34.30	100	1.85	34.30	27.44
149	2.69	34.54	150	2.70	34.54	27.56
198	2.93	34.66	200	2.95	34.67	27.65
297	3.89	34.86	300	3.90	34.86	27.71
393	3.90	34.91	400	3.90	34.91	27.75
590	3.61	34.91	600	3.60	34.91	27.78
787	3.49	34.91	800	3.50	34.91	27.79
887	3.38	34.91				

Station 2784; June 30; latitude 46°05′ N., longitude 46°06′ W., depth 778 meters, dynamic height 970.909 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	8.42	33.45	0	8.42	33.45	26.01
25	6.47	34.02	25	6.47	34.02	26.74
50	4.80	34.16	50	4.80	34.16	27.06
75	3.97	34.27	75	3.97	34.27	27.23
99	4.30	34.48	100	4.30	34.49	27.37
149	3.98	34.61	150	4.00	34.62	27.51
199	4.56	34.83	200	4.55	34.84	27.62
298	4.44	34.93	300	4.45	34.93	27.70
383	3.95	34.89	400	3.90	34.89	27.73
578	3.65	34.90	600	3.60	34.90	27.77
725	3.50	34.90				

Station 2785; June 30; latitude 46°06′ N., longitude 45°23′ W., depth 2,880 meters, dynamic height 970.888 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	10.09	34.05	0	10.09	34.05	26.21
25	7.29	34.08	25	7.29	34.08	26.67
50	4.83	34.26	50	4.83	34.26	27.13
75	3.02	34.27	75	3.02	34.27	27.32
100	2.56	34.33	100	2.56	34.33	27.41
150	3.71	34.67	150	3.71	34.67	27.58
200	3.53	34.75	200	3.53	34.75	27.66
300	3.71	34.87	300	3.71	34.87	27.74
386	3.60	34.89	400	3.60	34.89	27.76
580	3.52	34.89	600	3.50	34.89	27.77
774	3.47	34.90	800	3.45	34.90	27.78
969	3.43	34.90	1,000	3.40	34.90	27.79
1,358	3.29	34.91				

Station 2786; June 30; latitude 46°06′ N., longitude 44°42′ W., depth 3,200 meters, dynamic height 970.873 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	10.01	34.15	0	10.01	34.15	26.31
25	8.67	34.23	25	8.67	34.23	26.59
50	5.80	34.45	50	5.80	34.45	27.16
75	4.05	34.49	75	4.05	34.49	27.40
100	3.43	34.58	100	3.43	34.58	27.53
150	3.50	34.75	150	3.50	34.75	27.66
199	3.67	34.83	200	3.65	34.83	27.70
299	3.59	34.86	300	3.60	34.86	27.74
380	3.69	34.90	400	3.65	34.90	27.76
570	3.45	34.89	600	3.45	34.89	27.77
760	3.48	34.91	800	3.45	34.91	27.79
954	3.35	34.91	1,000	3.35	34.91	27.80
1,345	3.21	34.92				

Station 2787; June 30; latitude 46°18′ N., longitude 44°40′ W., depth 1,746 meters, dynamic height 970.869 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	9.94	34.27	0	9.94	34.27	26.42
23	9.72	34.32	25	9.70	34.33	26.50
47	5.91	34.44	50	5.60	34.45	27.19
70	4.34	34.54	75	4.15	34.56	27.44
93	3.69	34.63	100	3.70	34.65	27.56
140	3.68	34.76	150	3.70	34.78	27.67
187	3.83	34.84	200	3.85	34.85	27.70
280	3.92	34.90	300	3.90	34.90	27.74
365	3.70	34.90	400	3.60	34.90	27.77
550	3.46	34.89	600	3.45	34.89	27.77
736	3.41	34.90	800	3.40	34.91	27.80
926	3.38	34.92	1,000	3.35	34.92	27.81
1,314	3.22	34.92				

Station 2788; June 30; latitude 46°27′ N., longitude 44°39′ W., depth 622 meters, dynamic height 970.846 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	9.83	34.18	0	9.83	34.18	26.36
25	8.53	34.30	25	8.53	34.30	26.66
50	4.47	34.54	50	4.47	34.54	27.39
75	3.58	34.68	75	3.58	34.68	27.60
100	3.52	34.74	100	3.52	34.74	27.65
150	3.67	34.82	150	3.67	34.82	27.70
200	3.86	34.87	200	3.86	34.87	27.72
300	3.65	34.90	300	3.65	34.90	27.76
391	3.53	34.90	400	3.50	34.90	27.78
587	3.43	34.90	600	3.45	34.90	27.78

Station 2789; June 30; latitude 46°41′ N., longitude 44°36′ W., depth 220 meters, dynamic height 970.865 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
0	9.18	34.00	0	9.18	34.00	26.33
25	6.52	34.20	25	6.52	34.20	26.88
50	4.25	34.31	50	4.25	34.31	27.23
75	3.81	34.46	75	3.81	34.46	27.40
100	3.48	34.53	100	3.48	34.53	27.49
149	3.52	34.70	150	3.50	34.70	27.62
199	3.80	34.83	200	3.80	34.83	27.70

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
Station 2790; June 30; latitude 46°48′ N., longitude 44°35′ W., depth 165 meters, dynamic height 970.878 meters						
0	9.25	33.98	0	9.25	33.98	26.30
25	6.91	34.09	25	6.91	34.09	26.74
50	4.98	34.25	50	4.98	34.25	27.10
75	4.07	34.36	75	4.07	34.36	27.29
101	3.72	34.49	100	3.75	34.49	27.42
151	3.79	34.75	150	3.80	34.74	27.62
Station 2791; July 1; latitude 46°59′ N., longitude 44°33′ W., depth 132 meters, dynamic height 970.891 meters						
0	9.36	34.04	0	9.36	34.04	26.33
26	7.58	34.13	25	7.60	34.13	26.67
52	5.19	34.24	50	5.40	34.23	27.04
78	4.33	34.34	75	4.40	34.33	27.24
104	3.82	34.55	100	3.90	34.51	27.43
Station 2792; July 1; latitude 46°59′ N., longitude 45°11′ W., depth 165 meters, dynamic height 970.901 meters						
0	9.86	34.16	0	9.86	34.16	26.34
25	8.65	34.16	25	8.65	34.16	26.53
50	5.81	34.24	50	5.81	34.24	27.00
75	4.82	34.31	75	4.82	34.31	27.17
100	4.29	34.40	100	4.29	34.40	27.30
150	3.77	34.60	150	3.77	34.60	27.51
Station 2793; July 1; latitude 46°59′ N., longitude 45°22′ W., depth 220 meters, dynamic height 970.898 meters						
0	9.73	33.97	0	9.73	33.97	26.21
25	8.78	34.17	25	8.78	34.17	26.52
50	5.68	34.25	50	5.68	34.25	27.02
74	4.78	34.33	75	4.75	34.33	27.20
99	4.14	34.45	100	4.10	34.46	27.37
149	3.59	34.59	150	3.60	34.59	27.52
198	3.74	34.76	200	3.75	34.77	27.65
Station 2794; July 1; latitude 46°58′ N., longitude 45°55′ W., depth 302 meters, dynamic height 970.900 meters						
0	8.32	33.37	0	8.32	33.37	25.96
25	6.78	33.67	25	6.78	33.67	26.42
51	3.30	33.94	50	3.50	33.92	27.00
76	4.32	34.36	75	4.35	34.35	27.25
101	3.84	34.51	100	3.85	34.50	27.43
152	3.65	34.65	150	3.65	34.64	27.55
203	3.94	34.80	200	3.95	34.79	27.64
			(300)	3.75	34.88	27.74

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C	Salinity ‰	σ_t
Station 2795; July 1; latitude 46°58′ N., longitude 46°31′ W., depth 622 meters, dynamic height 970.895 meters						
0	6.95	32.94	0	6.95	32.94	25.83
25	0.97	33.16	25	0.97	33.16	26.59
50	−0.39	33.50	50	−0.39	33.50	26.94
75	2.21	34.12	75	2.21	34.12	27.28
100	3.68	34.50	100	3.68	34.50	27.44
150	3.48	34.65	150	3.48	34.65	27.58
201	3.83	34.80	200	3.85	34.80	27.66
301	3.77	34.88	300	3.75	34.88	27.74
397	3.62	34.90	400	3.65	34.90	27.76
594	3.50	34.91	600	3.50	34.91	27.79
Station 2796; July 1; latitude 46°58′ N., longitude 46°45′ W., depth 1,097 meters, dynamic height 970.892 meters						
0	6.84	33.14	0	6.84	33.14	25.99
25	5.22	33.31	25	5.22	33.31	26.34
50	3.65	34.06	50	3.65	34.06	27.10
75	1.83	34.22	75	1.83	34.22	27.38
100	2.51	34.45	100	2.51	34.45	27.51
150	2.60	34.61	150	2.60	34.61	27.63
201	3.15	34.73	200	3.15	34.73	27.68
301	3.67	34.86	300	3.65	34.86	27.73
402	3.60	34.88	400	3.60	34.88	27.76
600	3.58	34.90	600	3.60	34.90	27.77
796	3.54	34.92	800	3.55	34.92	27.79
992	3.41	34.92	1000	3.45	34.92	27.80
Station 2797; July 1; latitude 46°58′ N., longitude 47°09′ W., depth 622 meters, dynamic height 970.987 meters						
0	7.51	32.75	0	7.51	32.75	25.60
25	3.76	32.96	25	3.76	32.96	26.21
50	−1.53	33.28	50	−1.53	33.28	26.80
75	−1.53	33.48	75	−1.53	33.48	26.97
100	−0.70	33.68	100	−0.70	33.68	27.10
150	0.40	33.96	150	0.40	33.96	27.27
201	0.83	34.20	200	0.85	34.19	27.42
301	2.45	34.59	300	2.45	34.58	27.62
397	2.86	34.70	400	2.90	34.70	27.68
593	3.52	34.88	600	3.55	34.88	27.76
Station 2798; July 1; latitude 46°58′ N., longitude 47°48′ W., depth 165 meters, dynamic height 971.048 meters						
0	7.15	32.46	0	7.15	32.46	25.43
25	4.82	32.73	25	4.82	32.73	25.92
51	−0.87	32.88	50	−0.60	32.87	26.44
76	−1.56	33.12	75	−1.55	33.12	26.67
102	−1.60	33.28	100	−1.60	33.26	26.78
153	−0.64	33.57	150	−0.75	33.55	26.99

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2799; July 2; latitude 46°58′ N., longitude 48°17′ W., depth 119 meters, dynamic height 971.053 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.93	32.50	0	6.93	32.50	25.49
26	5.08	32.60	25	5.10	32.60	25.79
52	−0.76	32.83	50	−0.20	32.79	26.36
78	−1.44	33.10	75	−1.45	33.09	26.64
104	−1.31	33.33	100	−1.35	33.30	26.81

Station 2800; July 2; latitude 46°58′ N., longitude 48°42′ W., depth 91 meters, dynamic height 971.055 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.25	32.50	0	7.25	32.50	25.44
26	5.49	32.59	25	5.55	32.59	25.73
53	−0.01	32.74	50	0.60	32.72	26.26
79	−1.15	33.14	75	−1.05	33.06	26.61

Station 2801; July 2; latitude 47°16′ N., longitude 48°23′ W., depth 153 meters, dynamic height 971.034 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.72	32.49	0	6.72	32.49	25.51
26	2.93	32.70	25	3.00	32.69	26.07
51	−1.11	32.98	50	−0.90	32.97	26.53
77	−1.57	33.11	75	−1.55	33.11	26.66
102	−1.44	33.24	100	−1.50	33.23	26.75
143	−0.85	33.49	(150)	−0.75	33.53	26.98

Station 2802; July 2; latitude 47°30′ N., longitude 48°08′ W., depth 220 meters, dynamic height 971.035 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.13	32.62	0	7.13	32.62	25.56
24	5.94	32.68	25	5.75	32.69	25.79
49	−1.40	33.08	50	−1.45	33.09	26.64
73	−1.62	33.21	75	−1.60	33.21	26.74
97	−1.60	33.29	100	−1.60	33.30	26.81
146	−1.53	33.43	150	−1.50	33.45	26.94
194	−0.19	33.75	200	0.00	33.79	27.15

Station 2803; July 2; latitude 47°44′ N., longitude 47°53′ W., depth 320 meters, dynamic height 970.965 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.65	32.65	0	7.65	32.65	25.51
25	6.55	32.91	25	6.55	32.91	25.85
50	−1.15	33.34	50	−1.15	33.34	26.83
75	−1.07	33.56	75	−1.07	33.56	27.01
100	−0.56	33.74	100	−0.56	33.74	27.13
150	0.02	34.05	150	0.02	34.05	27.36
200	1.33	34.32	200	1.33	34.32	27.50
300	2.52	34.60	300	2.52	34.60	27.63

Station 2804; July 2; latitude 47° 54′ N., longitude 47° 42′ W., depth 622 meters, dynamic height 970.899 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.59	32.98	0	6.59	32.98	25.90
25	4.92	33.15	25	4.92	33.15	26.24
50	−0.24	33.71	50	−0.24	33.71	27.10
75	−1.06	33.92	75	−1.06	33.92	27.30
100	0.49	34.11	100	0.49	34.11	27.38
150	1.77	34.44	150	1.77	34.44	27.56
200	2.84	34.66	200	2.84	34.66	27.65
300	3.38	34.80	300	3.38	34.80	27.71
402	3.48	34.88	400	3.50	34.88	27.77
600	3.41	34.91	600	3.40	34.91	27.80

Station 2805; July 2; latitude 47° 57′ N,, longitude 47° 39′ W., depth 1,179 meters, dynamic height 970.896 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.51	32.95	0	6.51	32.95	25.89
25	2.31	33.25	25	2.31	33.25	26.57
50	2.30	33.75	50	2.30	33.75	26.97
75	−0.15	33.98	75	−0.15	33.98	27.32
99	0.66	34.16	100	0.70	34.17	27.42
149	1.86	34.46	150	1.90	34.47	27.58
199	2.70	34.63	200	2.70	34.64	27.64
298	3.42	34.82	300	3.45	34.82	27.72
394	3.51	34.88	400	3.50	34.88	27.77
590	3.50	34.90	600	3.50	34.90	27.78
785	3.37	34.90	800	3.35	34.90	27.79
981	3.30	34.90	1,000	3.30	34.90	27.80

Station 2806; July 2; latitude 48° 12′ N. longitude 47° 23′ W., depth 2,103 meters, dynamic height 970.867 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.67	33.13	0	6.67	33.13	26.01
24	1.07	33.65	25	1.05	33.66	26.99
49	0.74	34.11	50	0.75	34.12	27.38
73	0.88	34.23	75	0.90	34.24	27.46
97	1.46	34.35	100	1.55	34.37	27.52
146	2.36	34.57	150	2.45	34.59	27.62
195	3.05	34.71	200	3.10	34.72	27.68
292	3.60	34.84	300	3.60	34.84	27.72
330	3.57	34.85	400	3.50	34.86	27.75
505	3.40	34.86	600	3.35	34.87	27.77
688	3.33	34.89	800	3.35	34.90	27.79
872	3.34	34.90	1,000	3.30	34.90	27.80
1,255	3.26	34.90				

Station 2807; July 2; latitude 47° 48′ N., longitude 47° 20′ W., depth 549 meters, dynamic height 970.899 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.74	33.02	0	6.74	33.02	26.01
25	4.40	33.22	25	4.40	33.22	26.35
49	−0.27	33.66	50	−1.25	33.68	27.12
74	0.16	33.99	75	0.20	34.00	27.31
98	0.67	34.16	100	0.70	34.18	27.43
147	2.18	34.52	150	2.30	34.54	27.60
196	3.07	34.72	200	3.10	34.73	27.69
294	3.36	34.80	300	3.35	34.80	27.71
379	3.38	34.82	400	3.40	34.83	27.74
500	3.48	34.88				

Station 2808; July 3; latitude 47° 20′ N., longitude 47° 15′ W,, depth 320 meters dynamic height 970.961 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.02	32.24	0	8.02	32.24	25.12
25	1.91	33.03	25	1.91	33.03	26.42
49	−1.53	33.31	50	−1.50	33.32	26.83
74	−0.95	33.58	75	−0.95	33.59	27.03
99	−0.26	33.83	100	−0.20	33.84	27.20
148	0.80	34.13	150	0.85	34.14	27.38
197	1.25	34.30	200	1.30	34.31	27.49
296	2.53	34.60	300	2.60	34.61	27.63

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2809; July 24; latitude 53° 42′ N., longitude 55° 49′ W., depth 109 meters, dynamic height 1937.540 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	11.30	28.19	0	11.30	28.19	21.28
25	−0.31	32.24	25	−0.31	32.24	25.91
50	−1.37	32.87	50	−1.37	32.87	26.45
75	−1.50	33.02	75	−1.50	33.02	26.58
100	−1.54	33.07	100	−1.54	33.07	26.62

Station 2810; July 24; latitude 53° 49′ N., longitude 55° 34′ W., depth 208 meters, dynamic height 1937.486 meters.

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.01	30.98	0	8.01	30.98	24.14
25	0.17	32.56	25	0.17	32.56	26.15
50	−1.34	33.03	50	−1.34	33.03	26.59
74	−1.56	33.14	75	−1.55	33.14	26.68
99	−1.46	33.18	100	−1.45	33.18	26.71
149	−1.29	33.36	150	−1.30	33.36	26.85
198	−0.98	33.63	200	−0.95	33.64	27.07

Station 2811; July 24; latitude 53°55′ N., longitude 55°24′ W., depth 166 meters, dynamic height 1,937.463 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.54	31.26	0	8.54	31.26	24.28
25	3.08	32.52	25	3.08	32.52	25.72
51	−0.40	33.22	50	−0.25	33.21	26.69
76	−1.08	33.30	75	−1.05	33.30	26.79
102	−1.30	33.45	100	−1.30	33.43	26.91
153	−0.72	33.74	150	−0.75	33.72	27.12

Station 2812; July 24; latitude 54°08′ N., longitude 54°57′ W., depth 168 meters, dynamic height 1,937.446 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.06	31.40	0	7.06	31.40	24.61
26	0.09	32.70	25	0.40	32.69	26.25
51	−1.41	33.14	50	−1.40	33.14	26.67
77	−1.25	33.32	75	−1.25	33.32	26.81
103	−1.26	33.43	100	−1.25	33.42	26.90
154	−0.64	33.76	150	−0.70	33.73	27.13

Station 2813; July 24; latitude 54°22′ N., longitude 54°28′ W., depth 207 meters, dynamic height 1,937.451 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.44	31.84	0	7.44	31.84	24.90
23	0.10	32.40	25	0.00	32.46	26.08
45	−1.32	33.08	50	−1.35	33.12	26.66
68	−1.50	33.20	75	−1.50	33.24	26.76
90	−1.45	33.33	100	−1.35	33.38	26.87
135	−0.98	33.56	150	−0.35	33.73	27.11
176	1.36	34.25	(200)	3.50	34.62	27.55

Station 2814; July 25; latitude 54°36′ N., longitude 53°58′ W., depth 238 meters, dynamic height 1,937.427 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	5.99	31.78	0	5.99	31.78	25.03
25	−1.01	33.10	25	−1.01	33.10	26.63
51	−1.24	33.32	50	−1.25	33.32	26.81
76	−1.14	33.48	75	−1.15	33.48	26.95
101	−1.02	33.60	100	−1.00	33.59	27.03
152	−0.45	33.85	150	−0.50	33.84	27.21
203	0.51	34.08	200	0.45	34.07	27.34

Station 2815; July 25; latitude 54°47′ N., longitude 53°36′ W., depth 413 meters, dynamic height 1,937.377 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	4.66	32.04	0	4.66	32.04	25.39
25	0.74	33.27	25	0.74	33.27	26.69
50	1.24	33.68	50	1.24	33.68	26.98
76	0.03	33.90	75	0.05	33.90	27.24
101	0.82	34.02	100	0.80	34.01	27.28
151	2.06	34.36	150	2.00	34.35	27.47
202	3.57	34.63	200	3.50	34.61	27.55
303	4.14	34.83	300	4.15	34.82	27.64
398	3.86	34.88	400	3.85	34.88	27.72

Station 2816; July 25; latitude 54°54′ N., longitude 53°21′ W., depth 1,284 meters, dynamic height 1,937.312 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	5.68	32.71	0	5.68	32.71	25.80
25	5.49	34.06	25	5.49	34.06	26.89
50	4.08	34.43	50	4.08	34.43	27.34
76	3.37	34.57	75	3.35	34.56	27.52
101	3.95	34.82	100	3.95	34.82	27.66
151	3.95	34.82	150	3.95	34.82	27.66
202	3.88	34.86	200	3.90	34.86	27.71
303	3.74	34.84	300	3.75	34.85	27.71
401	3.66	34.86	400	3.65	34.86	27.73
601	3.48	34.86	600	3.50	34.86	27.75
799	3.44	34.89	800	3.45	34.89	27.77
998	3.44	34.89	1,000	3.45	34.89	27.77

Station 2817; July 25; latitude 55°01′ N., longitude 53°06′ W., depth 2,264 meters, dynamic height 1,937.291 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.37	34.16	0	6.37	34.16	26.87
25	4.54	34.24	25	4.54	34.24	27.14
50	3.85	34.61	50	3.85	34.61	27.51
76	3.81	34.73	75	3.80	34.73	27.61
101	4.23	34.84	100	4.25	34.84	27.65
151	4.06	34.83	150	4.05	34.83	27.66
201	3.88	34.87	200	3.90	34.87	27.71
302	3.73	34.85	300	3.75	34.85	27.71
398	3.60	34.88	400	3.60	34.88	27.75
596	3.44	34.86	600	3.45	34.86	27.75
794	3.41	34.86	800	3.40	34.86	27.75
990	3.40	34.91	1,000	3.40	34.91	27.80
1,488	3.26	34.90	1,500	3.25	34.90	27.80
1,987	2.87	34.92	2,000	2.85	34.92	27.85

Station 2818; July 25; latitude 55°12′ N., longitude 52°45′ W., depth 2,999 meters, dynamic height 1,937.266 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.48	34.10	0	7.48	34.10	26.66
25	6.07	34.29	25	6.07	34.29	27.00
50	3.88	34.64	50	3.88	34.64	27.53
75	3.42	34.72	75	3.42	34.72	27.64
100	3.71	34.86	100	3.71	34.86	27.73
150	3.57	34.84	150	3.57	34.85	27.73
201	3.48	34.84	200	3.50	34.84	27.73
301	3.43	34.87	300	3.45	34.87	27.75
393	3.41	34.87	400	3.40	34.87	27.76
574	3.37	34.90	600	3.40	34.90	27.79
743	3.39	34.90	800	3.40	34.90	27.79
903	3.36	34.89	1,000	3.30	34.89	27.79
1,383	3.19	34.91	1,500	3.20	34.91	27.82
1,883	3.17	34.91	2,000	3.05	34.91	27.83
2,583	2.48	34.92	2,500	2.55	34.92	27.88
3,033	2.12	34.89				

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2819; July 25; latitude 55°27′ N., longitude 52°18′ W., depth 3,198 meters, dynamic height 1,937.244 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	9.16	34.56	0	9.16	34.56	26.77
25	6.38	34.70	25	6.38	34.70	27.28
50	4.17	34.78	50	4.17	34.78	27.62
76	3.52	34.82	75	3.50	34.82	27.72
101	3.45	34.84	100	3.45	34.84	27.73
151	3.36	34.85	150	3.35	34.84	27.74
202	3.42	34.88	200	3.40	34.88	27.78
303	3.31	34.87	300	3.35	34.88	27.78
396	3.22	34.88	400	3.20	34.88	27.80
592	3.21	34.88	600	3.20	34.88	27.80
788	3.20	34.88	800	3.20	34.88	27.80
982	3.21	34.89	1,000	3.20	34.89	27.80
1,476	3.20	34.87	1,500	3.20	34.89	27.80
1,973	3.24	34.93	2,000	3.25	34.93	27.83
2,465	2.90	34.93	2,500	2.85	34.93	27.87
3,117	1.79	34.90	3,000	2.00	34.91	27.92

Station 2820; July 26; latitude 55°48′ N., longitude 51°37′ W., depth 3,456 meters, dynamic height 1,937.278 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	9.18	34.56	0	9.18	34.56	26.77
25	8.26	34.56	25	8.26	34.56	26.91
50	5.71	34.69	50	5.71	34.69	27.36
76	4.45	34.54	75	4.45	34.75	27.56
101	3.92	34.76	100	3.95	34.76	27.62
151	3.50	34.82	150	3.50	34.82	27.72
201	3.32	34.83	200	3.35	34.83	27.74
302	3.13	34.86	300	3.15	34.86	27.78
390	3.20	34.87	400	3.20	34.87	27.79
585	3.19	34.88	600	3.20	34.88	27.80
781	3.22	34.90	800	3.20	34.89	27.80
976	3.22	34.87	1,000	3.20	34.89	27.80
1,468	3.23	34.90	1,500	3.25	34.90	27.80
1,964	3.24	34.91	2,000	3.25	34.91	27.81
2,449	3.03	34.91	2,500	3.00	34.91	27.84
2,946	2.68	34.89	3,000	2.65	34.89	27.85
3,346	1.96	34.89				

Station 2821; July 26; latitude 56°37′ N., longitude 50°08′ W., depth 3,693 meters, dynamic height 1,937.277 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.60	34.61	0	8.60	34.62	26.91
24	8.17	34.66	25	8.10	34.66	27.01
49	4.70	34.74	50	4.65	34.74	27.53
73	3.81	34.80	75	3.80	34.80	27.67
98	3.48	34.82	100	3.45	34.82	27.72
147	3.36	34.84	150	3.35	34.84	27.74
195	3.40	34.85	200	3.40	34.85	27.75
293	3.31	34.88	300	3.30	34.88	27.79
383	3.28	34.87	400	3.25	34.88	27.79
574	3.27	34.89	600	3.25	34.88	27.79
765	3.20	34.88	800	3.20	34.88	27.79
955	3.24	34.89	1,000	3.25	34.89	27.79
1,442	3.22	34.89	1,500	3.25	34.89	27.79
1,933	3.29	34.89	2,000	3.30	34.89	27.79
2,313	3.22	34.88	2,500	3.15	34.89	27.80
2,863	2.86	34.91	3,000	2.75	34.91	27.86
3,422	2.24	34.91	(3,500)	2.10	34.91	27.91

Station 2822; July 26–27; latitude 57°25′ N., longitude 48°47′ W., depth 3,428 meters, dynamic height 1,937.272 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	7.69	34.61	0	7.69	34.61	27.03
24	7.62	34.63	25	7.60	34.63	27.06
48	4.96	34.71	50	4.80	34.72	27.50
71	3.84	34.80	75	3.80	34.80	27.67
95	3.54	34.83	100	3.55	34.84	27.72
143	3.47	34.87	150	3.45	34.87	27.76
191	3.37	34.88	200	3.35	34.88	27.77
286	3.28	34.88	300	3.25	34.88	27.78
351	3.26	34.88	400	3.25	34.88	27.78
531	3.22	34.88	600	3.20	34.88	27.79
713	3.20	34.88	800	3.20	34.88	27.79
898	3.18	34.89	1,000	3.20	34.88	27.79
1,368	3.16	34.87	1,500	3.20	34.88	27.79
1,853	3.26	34.89	2,000	3.25	34.90	27.80
2,242	3.20	34.92	2,500	3.05	34.91	27.83
2,709	2.87	34.90	3,000	2.55	34.91	27.88
3,072	2.46	34.91				

Station 2823; July 27; latitude 58°14′ N., longitude 47°29′ W., depth 3,123 meters, dynamic height 1,937.283 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.82	34.46	0	6.82	34.46	27.04
25	6.69	34.47	25	6.69	34.47	27.07
50	5.11	34.59	50	5.11	34.59	27.36
76	4.52	34.76	75	4.55	34.76	27.56
101	3.99	34.82	100	4.00	34.81	27.66
151	3.98	34.89	150	4.00	34.89	27.72
201	3.88	34.89	200	3.90	34.89	27.73
302	3.81	34.91	300	3.85	34.91	27.75
390	3.77	34.91	400	3.75	34.91	27.76
584	3.46	34.90	600	3.45	34.90	27.78
777	3.35	34.89	800	3.35	34.89	27.78
969	3.37	34.90	1,000	3.35	34.90	27.79
1,461	3.20	34.88	1,500	3.20	34.90	27.81
1,956	3.19	34.91	2,000	3.20	34.91	27.82
2,451	2.84	34.93	2,500	2.80	34.92	27.86
2,750	2.46	34.90	3,000	1.80	34.90	27.93
3,050	1.64	34.90				

Station 2824; July 27; latitude 58°40′ N., longitude 46°18′ W., depth 2,511 meters, dynamic height 1,937.265 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.98	34.45	0	6.98	34.45	27.01
25	6.59	34.45	25	6.59	34.45	27.06
51	5.29	34.67	50	5.30	34.66	27.39
76	5.08	34.85	75	5.10	34.85	27.57
101	5.03	34.99	100	5.05	34.98	27.67
152	4.74	35.00	150	4.75	35.00	27.72
203	4.55	34.99	200	4.55	34.99	27.74
304	4.27	34.96	300	4.30	34.96	27.74
399	4.09	34.96	400	4.10	34.95	27.76
596	3.77	34.93	600	3.75	34.93	27.77
793	3.50	34.89	800	3.50	34.89	27.77
987	3.43	34.93	1,000	3.45	34.93	27.80
1,482	3.17	34.92	1,500	3.15	34.92	27.83
1,980	2.84	34.91	2,000	2.85	34.91	27.85
2,454	2.12	34.90	(2,500)	2.00	34.90	27.91

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2825; July 27; latitude 59°02′ N., longitude 45°38′ W., depth 2,436 meters, dynamic height 1,937.280 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.62	34.52	0	6.62	34.52	27.12
25	6.48	34.56	25	6.48	34.56	27.16
50	6.52	34.83	50	6.52	34.83	27.37
76	5.43	34.94	75	5.45	34.94	27.59
101	5.43	35.03	100	5.45	35.03	27.66
151	5.12	35.02	150	5.15	35.02	27.70
201	4.76	34.98	200	4.75	34.98	27.70
302	4.27	34.96	300	4.30	34.96	27.74
401	3.83	34.90	400	3.85	34.90	27.74
600	3.69	34.93	600	3.70	34.93	27.78
798	3.41	34.89	800	3.40	34.89	27.78
995	3.37	34.90	1,000	3.35	34.90	27.79
1,490	3.27	34.91	1,500	3.25	34.91	27.81
1,982	3.01	34.92	2,000	3.00	34.92	27.85
2,378	2.38	34.90				

Station 2826; July 28; latitude 59°17′ N., longitude 45°10′ W., depth 1,940 meters, dynamic height 1937.301 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.95	34.77	0	6.95	34.77	27.27
24	6.93	34.77	25	6.95	34.77	27.27
48	6.93	34.77	50	6.90	34.77	27.28
71	6.88	34.77	75	6.85	34.77	27.28
95	6.83	34.79	100	6.80	34.80	27.31
143	5.98	34.92	150	5.90	34.94	27.54
191	5.42	35.04	200	5.35	35.03	27.67
286	4.80	35.00	300	4.75	35.00	27.72
370	4.50	34.99	400	4.40	34.99	27.75
557	4.04	34.95	600	3.95	34.93	27.75
744	3.65	34.89	800	3.60	34.89	27.76
933	3.50	34.92	1,000	3.45	34.92	27.80
1,416	3.13	34.93	1,500	3.05	34.92	27.84
1,808	2.64	34.92				

Station 2827; July 28; latitude 59°29′ N., longitude 44°50′ W., depth, 1,177 meters, dynamic height 1937.374 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	5.69	34.55	0	5.69	34.55	27.26
24	5.62	34.53	25	5.65	34.53	27.24
48	5.82	34.61	50	5.90	34.52	27.29
72	6.10	34.71	75	6.10	34.72	27.34
96	6.02	34.74	100	6.00	34.74	27.37
144	5.61	34.87	150	5.60	34.88	27.52
191	5.44	34.93	200	5.40	34.93	27.59
287	5.12	34.95	300	5.10	34.95	27.64
384	5.08	35.01	400	5.05	35.01	27.70
575	4.75	35.00	600	4.75	35.00	27.72
767	4.62	34.99	800	4.60	34.98	27.72
959	4.35	34.97	(1,000)	4.30	34.97	27.75

Station 2828; July 28; latitude 59°35′ N., longitude 44°41′ W., depth 176 meters, dynamic height 1937.491 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.59	30.65	0	0.59	30.65	24.59
24	−1.33	32.81	25	−1.35	32.82	26.42
48	−1.45	32.99	50	−1.45	33.00	26.56
71	−1.45	33.06	75	−1.45	33.08	26.63
95	−1.37	33.21	100	−1.30	33.28	26.78
143	3.01	34.43	(150)	3.50	34.49	27.45

Station 2829; July 28; latitude 59°38′.5 N., longitude 44°36′ W., depth 152 meters, dynamic height 1937.490 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.38	30.13	0	−0.38	30.13	24.24
24	−0.82	32.57	25	−0.80	32.59	26.22
49	−0.88	33.23	50	−0.85	33.24	26.74
73	−0.66	33.36	75	−0.65	33.36	26.83
98	−0.62	33.38	100	−0.40	33.40	26.86
132	1.96	34.13	(150)	3.05	34.40	27.42

Station 2830; July 28; latitude 59°41′ N., longitude 44°31′ W., depth 166 meters, dynamic height 1937.477 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	−0.42	29.82	0	−0.42	29.82	23.97
22	−1.05	32.51	25	−1.05	32.55	26.19
44	−0.98	32.99	50	−0.70	33.13	26.65
65	0.61	33.58	75	1.20	33.82	27.11
87	1.66	34.05	100	1.85	34.10	27.28
131	2.21	34.18	(150)	2.40	34.22	27.34

Station 2831; July 30; latitude 59°06′ N., longitude 53°38′ W., depth 3,200 meters, dynamic height 1937.267 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	8.19	34.54	0	8.19	34.54	26.90
25	6.56	34.63	25	6.56	34.63	27.22
50	4.36	34.76	50	4.36	34.76	27.58
75	3.66	34.83	75	3.66	34.83	27.71
101	3.69	34.87	100	3.70	34.87	27.74
151	3.61	34.89	150	3.60	34.89	27.76
201	3.53	34.90	200	3.55	34.90	27.77
302	3.40	34.88	300	3.40	34.88	27.78
395	3.30	34.88	400	3.30	34.88	27.79
593	3.22	34.88	600	3.20	34.87	27.79
790	3.20	34.87	800	3.20	34.87	27.79
988	3.17	34.89	1,000	3.20	34.87	27.79
1,482	3.17	34.86	1,500	3.20	34.87	27 79
1,976	3.28	34.88	2,000	3.30	34.88	27.79
2,446	3.06	34.92	(2,500)	3.05	34.92	27 84

Station 2832; July 30; latitude 60°04′ N., longitude 54°27′ W., depth 3,276 meters, dynamic height 1,937.286 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.62	33.92	0	6.62	33.92	26.65
25	6.51	34.26	25	6.51	34.26	26.93
50	3.47	34.56	50	3.47	34.56	27.51
75	3.69	34.76	75	3.69	34.76	27.65
100	3.73	34.81	100	3.73	34.81	27.68
150	4.06	34.90	150	4.06	34.90	27.72
199	4.17	34.94	200	4.15	34.94	27.74
299	4.13	34.95	300	4.15	34.95	27.75
394	3.88	34.93	400	3.85	34.93	27.77
592	3.53	34.92	600	3.50	34.91	27.79
789	3.30	34.89	800	3.30	34.89	27.79
986	3.24	34.89	1,000	3.25	34.89	27.79
1,491	3.17	34.86	1,500	3.20	34.88	27.80
1,988	3.25	34.91	2,000	3.25	34.91	27.81
2,469	2.93	34.92	(2,500)	2.95	34.92	27.85

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2833; July 30; latitude 60°56′ N., longitude 55°12′ W., depth 2,888 meters, dynamic height 1,937.252 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.52	33.80	0	6.52	33.80	26.56
25	4.53	34.18	25	4.53	34.18	27.10
50	2.78	34.50	50	2.78	34.50	27.52
75	3.34	34.68	75	3.34	34.68	27.62
101	4.04	34.83	100	4.05	34.82	27.66
151	4.06	34.88	150	4.05	34.88	27.71
201	4.18	34.93	200	4.15	34.93	27.74
302	3.85	34.92	300	3.85	34.92	27.76
394	3.76	34.91	400	3.75	34.92	27.77
592	3.53	34.92	600	3.50	34.92	27.80
789	3.46	34.92	800	3.45	34.92	27.80
986	3.33	34.92	1,000	3.35	34.92	27.81
1,494	3.17	34.87	1,500	3.20	34.92	27.83
1,992	3.18	34.93	2,000	3.20	34.93	27.84
2,481	2.76	34.93	(2,500)	2.75	34.93	27.88

Station 2834; July 31; latitude 61°49′ N., longitude 56°30′ W., depth 2,634 meters, dynamic height 1,937.291 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	6.22	33.90	0	6.22	33.90	26.68
25	5.96	33.93	25	5.96	33.93	26.75
51	2.29	34.36	50	2.30	34.33	27.44
76	2.60	34.51	75	2.60	34.51	27.56
101	2.90	34.64	100	2.90	34.63	27.63
152	4.12	34.87	150	4.10	34.86	27.69
203	4.19	34.91	200	4.20	34.92	27.73
304	3.93	34.89	300	3.95	34.90	27.73
393	3.99	34.93	400	4.00	34.93	27.76
589	3.65	34.91	600	3.65	34.91	27.77
786	3.67	34.92	800	3.65	34.92	27.78
982	3.49	34.92	1,000	3.50	34.92	27.80
1,497	3.28	34.88	1,500	3.30	34.92	27.82
1,996	3.05	34.92	2,000	3.05	34.92	27.84
2,495	2.46	34.92	2,500	2.45	34.92	27.89

Station 2835; July 31; latitude 62°58′ N., longitude 57°02′ W., depth 2,246 meters, dynamic height 1,937.323 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	5.43	33.56	0	5.43	33.56	26.51
27	4.12	33.76	25	4.20	33.75	26.80
53	2.45	34.22	50	2.45	34.15	27.27
80	2.87	34.45	75	2.75	34.42	27.47
106	3.30	34.58	100	3.25	34.56	27.53
161	3.58	34.72	150	3.50	34.70	27.62
214	3.83	34.81	200	3.75	34.79	27.66
320	4.20	34.91	300	4.20	34.90	27.71
415	4.13	34.91	400	4.15	34.91	27.72
622	3.79	34.88	600	3.85	34.91	27.75
830	3.76	34.92	800	3.75	34.92	27.77
1,038	3.52	34.91	1,000	3.60	34.92	27.79
1,647	3.26	34.92	1,500	3.30	34.92	27.82
2,131	2.78	34.92	2,000	3.00	34.92	27.85

Station 2836; July 31–Aug. 1; latitude 63°58′ N., longitude 57°15′ W., depth 1,069 meters, dynamic height 1,937.432 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	4.21	33.23	0	4.21	33.23	26.38
26	2.46	33.36	25	2.50	33.36	26.64
52	0.39	33.65	50	0.40	33.61	26.99
78	0.60	33.77	75	0.60	33.76	27.09
104	0.87	33.94	100	0.80	33.91	27.20
157	1.70	34.18	150	1.60	34.16	27.35
208	2.39	34.39	200	2.30	34.37	27.47
312	3.46	34.17	300	3.35	34.66	27.60
427	4.54	34.92	400	4.35	34.89	27.68
639	4.23	34.89	600	4.30	34.89	27.69
853	3.94	34.89	800	4.00	34.89	27.72
1,067	3.49	34.91	1,000	3.65	34.91	27.77

Station 2837; Aug. 1; latitude 64°52′ N., longitude 57°27′ W., depth 689 to 716 meters, dynamic height 1,937.398 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	4.52	33.29	0	4.52	33.29	26.39
27	0.95	33.67	25	1.00	33.65	26.98
54	0.24	33.87	50	0.30	33.85	27.18
81	−0.16	33.90	75	−0.10	33.89	27.23
107	−0.11	34.05	100	−0.15	34.00	27.33
162	0.47	34.19	150	0.25	34.15	27.43
215	1.92	34.40	200	1.35	34.34	27.51
322	4.53	34.85	300	4.25	34.78	27.60
423	4.66	34.91	400	4.65	34.91	27.67
634	3.11	34.77	600	3.35	34.79	27.70

Station 2838; Aug. 1; latitude 65°48′ N., longitude 57°30′ W., depth 576 meters, dynamic height 1,937.450 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.28	31.25	0	0.28	31.25	25.09
26	0.32	33.40	25	0.35	33.38	26.80
51	−0.19	33.70	50	−0.15	33.70	27.09
77	−1.15	33.74	75	−1.15	33.74	27.16
102	−1.43	33.77	100	−1.40	33.77	27.18
153	−0.56	33.92	150	−0.60	33.91	27.27
204	0.11	34.10	200	0.05	34.09	27.39
306	2.94	34.51	300	2.90	34.50	27.52
396	2.50	34.60	400	2.45	34.60	27.63
544	1.13	34.52				

Station 2839; Aug. 1; latitude 65°56′ N., longitude 56°58′ W., depth 632 meters, dynamic height 1,937.462 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	0.62	31.05	0	0.62	31.05	24.91
25	3.43	33.49	25	3.43	33.48	26.65
50	1.85	33.58	50	1.85	33.58	26.87
75	0.74	33.70	75	0.74	33.70	27.04
100	0.18	33.82	100	0.18	33.82	27.16
150	1.00	34.02	150	1.00	34.02	27.27
199	1.87	34.32	200	1.90	34.32	27.45
299	3.21	34.63	300	3.25	34.63	27.58
377	3.51	34.69	400	3.35	34.67	27.60
566	0.64	34.47	(600)	0.45	34.46	27.66

Table of oceanographic data—Continued

STATIONS OCCUPIED IN 1938—Continued

Station 2840; Aug. 1; latitude 66°03′ N., longitude 56°28′ W., depth 569 meters, dynamic height 1,937.426 meters

Observed values			Scaled values			
Depth meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	4.01	33.11	0	4.01	33.11	26.30
25	3.89	33.37	25	3.89	33.37	26.52
50	1.36	33.55	50	1.36	33.55	26.88
75	0.44	33.78	75	0.44	33.78	27.11
101	0.34	33.87	100	0.35	33.86	27.19
151	1.37	34.19	150	1.30	34.17	27.37
201	2.22	34.44	200	2.20	34.44	27.53
302	2.63	34.57	300	2.60	34.57	27.59
399	3.23	34.72	400	3.25	34.72	27.65
549	2.87	34.75				

Station 2841; Aug. 1–2; latitude 66°07′ N., longitude 56°10′ W., depth 166 meters, dynamic height 1,937.429 meters

Observed values			Scaled values			
Depth meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.26	33.21	0	3.26	33.21	26.45
20	3.21	33.22	25	2.90	33.25	26.53
46	1.09	33.47	50	0.95	33.52	26.87
71	0.65	33.68	75	0.65	33.71	27.05
96	1.09	33.90	100	1.15	33.92	27.18
147	1.46	34.11	150	1.50	34.12	27.32

Station 2842; Aug. 2; latitude 66°12′ N., longitude 55°50′ W., depth 175 meters, dynamic height 1,937.409 meters

Observed values			Scaled values			
Depth meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.04	33.49	0	3.04	33.49	26.70
26	2.39	33.65	25	2.40	33.64	26.87
52	0.86	33.78	50	0.90	33.77	27.08
77	0.52	33.84	75	0.55	33.84	27.16
103	0.16	33.87	100	0.20	33.86	27.20
155	0.01	34.00	150	0.05	33.99	27.31

Station 2843; Aug. 2; latitude 66°16′ N., longitude 55°31′ W., depth 193 meters, dynamic height 1,937.408 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth, meters	Temperature ° C.	Salinity ‰	σ_t
0	3.29	33.61	0	3.29	33.61	26.77
26	3.29	33.64	25	3.30	33.64	26.79
51	1.95	33.80	50	2.00	33.80	27.03
77	0.62	33.86	75	0.65	33.85	27.16
103	0.05	33.97	100	0.10	33.97	27.28
154	−0.15	33.99	150	−0.15	33.99	27.32
180	−0.18	34.04				

Station 2844; Aug. 2; latitude 66°21′ N., longitude 55°11′ W., depth 182 meters, dynamic height 1937.396 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth meters	Temperature ° C.	Salinity ‰	σ_t
0	3.11	33.65	0	3.11	33.65	26.82
20	2.43	33.70	25	2.20	33.73	26.95
46	1.23	33.85	50	1.10	33.86	27.14
72	0.48	33.88	75	0.45	33.88	27.19
97	0.11	33.98	100	0.05	33.99	27.31
148	−0.24	34.06	150	−0.25	34.05	27.37
174	−0.27	34.05				

Station 2845; Aug. 2; latitude 66°30′ N., longitude 55°01′ W., depth 173 meters, dynamic height 1937.402 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth meters	Temperature ° C.	Salinity ‰	σ_t
0	2.91	33.56	0	2.91	33.56	26.77
25	2.50	33.65	25	2.50	33.65	26.87
50	1.70	33.74	50	1.70	33.74	27.00
75	1.35	33.82	75	1.35	33.82	27.09
99	0.44	33.91	100	0.45	33.92	27.22
149	−0.25	34.15	150	−0.25	34.16	27.46

Station 2846; Aug. 2; latitude 66°44′ N., longitude 54°21′ W., depth 35 m., dynamic height 1937.408 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth meters	Temperature ° C.	Salinity ‰	σ_t
0	2.98	33.44	0	2.98	33.44	26.66
13	2.94	33.45	25	2.80	33.55	26.77
26	2.76	33.56				

Station 2847; Aug. 2; latitude 66°45′ N., longitude 54°05′ W., depth 172 meters, dynamic height 1937.439 meters

Observed values			Scaled values			
Depth, meters	Temperature ° C.	Salinity ‰	Depth meters	Temperature ° C.	Salinity ‰	σ_t
0	3.64	32.85	0	3.64	32.85	26.14
24	3.43	33.01	25	3.40	33.02	26.29
49	3.08	33.29	50	3.10	33.30	26.54
73	2.95	33.43	75	2.95	33.44	26.66
98	2.86	33.49	100	2.85	33.49	26.71
132	2.77	33.50	(150)	2.75	33.50	26.73

Oxygen data collected on post-season cruise, 1938

Depth, meters	Oxygen		Depth, meters	Oxygen	
	ml./liter	Percent saturation		ml./liter	Percent saturation
Station 2821; July 26; latitude 56°37′ N., longitude 50°08′ W., depth 3,693 meters					
98	6.62	90	955	6.51	87.5
195	6.43	87	1,442	6.51	87.5
293	6.35	86	1,933	6.45	87
383	6.25	84	2,313	6.75	91
574	6.25	84	2,863	6.31	84
765	6.53	88	3,422	6.23	82
Station 2822; July 26–27, latitude 57°25′ N., longitude 48°47′ W., depth 3,428 meters					
95	6.64	90	898	6.68	90
191	6.56	89	1,368	6.73	90
286	6.63	89	1,853	6.58	89
351	6.55	88	2,242	6.10	82
531	6.67	90	2,709	6.20	83
713	6.64	89	3,072	6.30	83
Station 2823; July 27; latitude 58°14′ N., longitude 47°29′ W., depth 3,123 meters					
101	6.46	88	969	6.36	86
201	6.64	91	1,461	6.46	87
302	6.60	90	1,956	6.31	85
390	6.63	90	2,451	6.20	83
584	6.53	88	2,750	6.14	81
777	6.57	89	3,050	6.48	84
Station 2831; July 30; latitude 59°06′ N., longitude 53°38′ W., depth 3,200 meters					
101	6.41	87	790	6.46	87
201	6.35	86	988	6.46	87
302	6.38	86	1,482	6.42	86
395	6.50	88	1,976	6.53	88
593	6.52	88	2,446	6.08	81
Station 2832; July 30; latitude 60°04′ N., longitude 54°27′ W., depth 3,276 meters					
100	6.44	88	789	6.35	86
199	6.42	88	986	6.31	85
299	6.31	87	1,491	6.41	86
394	6.34	87	1,988	6.02	81
592	6.62	90	2,469	6.20	83
Station 2833; July 30; latitude 60°56′ N., longitude 55°12′ W., depth 2,888 meters					
101	6.41	88	789	6.08	82
201	6.31	87	986	6.14	83
302	6.30	86	1,494	6.33	85
394	6.20	84	1,992	6.06	81
592	6.25	85	2,481	5.85	78
Station 2834; July 31; latitude 61°49′ N., longitude 56°30′ W., depth 2,634 meters					
101	6.25	83	786	6.30	86
152	6.25	86	982	6.08	82
203	6.38	88	1,497	5.97	80
304	6.21	85	1,996	6.03	81
393	6.20	85	2,495	6.20	82
589	6.36	86			
Station 2835; July 31; latitude 62°58′N., longitude 57°02′W., depth 2,246 meters					
106	6.18	83	622	5.98	81
161	6.06	82	830	6.11	83
214	6.18	84	1,038	6.05	82
320	6.18	85	1,647	6.11	82
415	6.17	85	2,131	6.23	83
Station 2836; July 31–Aug. 1; latitude 63°58′N., longitude 57°15′W., depth 1,069 meters					
104	6.56	83	427	6.10	85
157	6.68	86	639	6.02	83
208	6.60	87	853	5.97	82
312	6.40	86	1,067	5.80	78
Station 2837; Aug. 1; latitude 64°52′ N., longitude 57°27′ W., depth 716 meters					
107	6.73	83	322	5.86	81
132	6.20	77.5	423	6.26	87
215	6.15	80	634	5.75	77
Station 2838; Aug. 1; latitude 65°48′ N., longitude 57°30′W., depth 576 meters					
102	6.65	79	306	6.66	89
153	6.65	81	396	5.97	79
204	6.60	84	544	5.13	65

Contribution No. 231

DECOMPOSITION OF CHITIN BY MARINE BACTERIA

CHARLES W. HOCK

(*From the Woods Hole Oceanographic Institution,*[1] *Woods Hole, Mass.*)

Chitin is an important constituent of the exoskeletons of many marine animals. For example, the shell of the horseshoe crab, *Limulus polyphemus*, consists on an average of 25 per cent chitin. Due to the death of marine inhabitants, and to the production of chitinous casts during the developmental stages of certain species, large quantities of chitin are released annually. If this material were not decomposed, much carbon and nitrogen would be withheld from the cycles of these elements in the sea. Analyses of marine sediments indicate, however, that relatively little chitin accumulates there; it must, therefore, be broken down into simpler chemical compounds, or mineralized.

Decomposition of chitin by mixed or pure cultures of marine bacteria has been demonstrated by several investigators (2, 4, 12, 14, 16, 17), whose observations indicate that chitin-decomposing bacteria have a worldwide distribution in the sea. The present investigation was undertaken to study the distribution of these bacteria in a relatively restricted region of the sea, and to follow the breakdown of chitinous materials in natural media from this same locality.

Chitin has an elementary composition of $C_{32}H_{54}O_{21}N_4$ (6). It is a tough leathery substance, insoluble in water, in concentrated alkalis and in the usual organic solvents. By hydrolysis with concentrated acid it yields glucosamine and acetic acid in proportions which indicate that there is an acetyl group for each glucosamine residue. So far no essential differences have been found in the chitin from animal or vegetable sources (5, 7).

Isolation of Chitin-Decomposing Bacteria

Purified chitin, used in making culture media for the detection and isolation of chitin-decomposing bacteria, was prepared from horseshoe crab shells by the methods of Benton (1) and ZoBell and Rittenberg (17). The shells were treated successively, for prolonged periods, with 1 per cent hydrochloric acid, 2 per cent potassium hydroxide and 95 per cent ethyl alcohol. The snowy-white material which remained reacted positively to simple qualitative tests for chitin (3).

[1] Contribution No. 231.

Liquid culture media were prepared by partly covering 1 × 5 cm. strips of purified chitin, in test tubes, with sea water, or with sea water containing 0.1 per cent concentrations of additional nutrients such as dextrose, peptone, or ammonium chloride. In some cases a small amount (0.005 per cent) of phosphate was added to the sea water to eliminate any effect due to lack of available phosphorus. The medium best suited for the detection of chitin-decomposing bacteria consisted of a strip of chitin partly covered with a solution used by Waksman (14), and having the following composition:

Glucose	1 gram
Peptone	1 gram
K_2HPO_4	0.05 gram
Sea water (filtered)	1,000 ml.

Solid media were prepared from the liquid culture media either by the addition of 15 grams of agar to each liter of solution or by diffusion of the nutrient solutions through silica gels. Where solid media were employed strips of sterile purified chitin were placed on the surface of the hardened gel. The silica gel plates were prepared under as nearly aseptic conditions as possible; all other media were sterilized by autoclaving for 20 minutes at 120° C.

One additional solid medium was found useful for the rapid detection of chitin-decomposing bacteria. It was prepared by uniformly dispersing chitin in agar according to the following procedure. Fifteen grams of purified chitin were added to 150 ml. of 1 : 1 sulfuric acid and kept overnight in the refrigerator. The chitin was dissolved by this treatment but analyses showed that it was not altered chemically, i.e. hydrolyzed. The following day the chitin was precipitated by the addition of approximately 140 ml. of 20 per cent potassium hydroxide. The precipitate was placed on a Büchner funnel and washed repeatedly with distilled water until the filtrate was neutral to litmus. Thirty-five grams of the chitin, as removed from the filter, were then added to agar which contained 0.1 per cent glucose, 0.1 per cent peptone, and 0.005 per cent dipotassium hydrogen phosphate. After autoclaving, the agar was thoroughly shaken to redistribute the chitin, and Petri plates were prepared. In this condition the medium was of a uniform milky-white opacity. When chitin-decomposing bacteria grew on the surface of this agar they dissolved the chitin, thereby producing a clear halo around each colony. By noting the length of time necessary for the appearance of halos the rates of bacterial activity could be estimated. Bacteria which decomposed chitin rapidly often produced a halo after two days' growth whereas others required eight to ten days for a positive test. Although bacteria which were

unable to decompose chitin often grew well on the medium, they did not alter it in appearance. Results obtained with this agar confirmed, without exception, the results obtained with other solid and liquid media.

In order to test a given sample of marine material for chitin-decomposing bacteria, several different media were inoculated. The inoculated media were incubated at room temperature and examined periodically for evidence of chitin breakdown. Growth was slow in the medium consisting of only chitin in sea water, whereas the same bacteria decomposed the chitin more rapidly when additional nutrients were present.

Visible dissolution of the chitin, either in liquid medium or on a solid agar surface, was indisputable evidence that the chitin was being attacked. To detect incipient decomposition a hand lens was helpful. The liberation of ammonia from media lacking peptone or nitrate, reducing substances from media lacking glucose, or a pronounced change in acidity, were further reliable evidence of chitin decomposition. The mere growth of bacteria in a medium consisting of only chitin in sea water is an unreliable criterion of decomposition, since bacteria may persist in this medium for a long period without altering the chitin.

In preliminary studies, cultures of bacteria showing no evidence of chitin-decomposition were kept one year before being discarded as negative. It became evident, however, that several weeks were adequate for detecting the chitin-decomposing capacity of most species. To obtain pure cultures of bacteria a second tube of enriched medium was inoculated with a loopful of material from an original positive culture. Growth from this tube was then streaked on nutrient agar plates and the different types of colonies which developed were retested for their ability to attack chitin. In later experiments pure cultures were obtained more quickly by streaking growth from enriched cultures on agar medium containing precipitated chitin. This medium was highly satisfactory for separating the chitin-decomposing bacteria from others which had persisted but which were not attacking the chitin.

Occurrence of Chitin-Decomposing Bacteria in the Sea

The number of chitin-decomposing bacteria in sand, mud, and water was determined by dilution culture methods. To increase the probability of detecting chitin-decomposing bacteria, several kinds of culture media were inoculated with each dilution of the sample. In making quantitative determinations only visible breakdown of the chitin was considered a positive test.

An 11 cm. core of sand, taken from a littoral zone in the vicinity of Woods Hole harbor on July 31, 1939, was found to be a relatively rich source of chitin-decomposing bacteria. At the top of the core there were at least 60,000 of these bacteria per gram of sand, this number decreasing to 6,000 per gram at a depth of 5 cm., and to 600 per gram at 11 cm.

A sample of mud was collected on July 7, 1939, at latitude 40° 38′ N. × 71° 39′ W. and at a depth of 878 meters. Chitin-decomposing bacteria were relatively abundant in the upper layer of the core (125 cells per gram), but dropped to less than 5 cells per gram at depths of 5 and 11 cm. Both in sand and in mud the number of chitin-decomposing bacteria decreased sharply with core depth.

On August 2, 1939, a sample of water was collected at 5 fathoms NE. of Lambert's Cove, Martha's Vineyard, one mile offshore, in a locality where the water is naturally well stirred. Dilution culture methods indicated the presence of 150 bacteria per ml. of water.

Chitin-decomposing bacteria were isolated from other samples of sand, mud and water, in addition to those described above. There was no correlation noted between abundance of the bacteria in the sediments and depth of the overlying water. In addition to bacteria isolated from media collected in the vicinity of Woods Hole a few cultures of chitin-decomposing bacteria were isolated from samples of water brought from tropical regions by the research ship "Atlantis."

Dead and decomposing horseshoe crabs offered an excellent source of chitin-decomposing bacteria. A single attempt to isolate these bacteria from a jar of dead copepods was unsuccessful.

That animals may possess intestinal fauna and flora capable of breaking down certain foods ingested by the host is well established. It has been demonstrated, for example, that wood-boring termites harbor in their intestinal tract microörganisms which perform for their host the invaluable function of digesting cellulose (15). Since a similar condition in relation to chitin might exist in marine organisms, the intestinal contents of several common marine animals were examined for chitin-decomposing bacteria. Using methods already described for their detection, chitin-decomposing bacteria were found in the intestinal contents of *Venus mercenaria mercenaria*, *Ostrea virginica*, *Loligo pealeii pealeii*, *Ovalipes ocellatus ocellatus*, *Mustelus mustelus*, *Raia erinacea* and *Spheroides maculatus*. In this investigation, all animals whose intestinal contents were examined for chitin-decomposing bacteria were found to possess them. The presence of these bacteria in the intestines of marine animals has previously been demonstrated by Benton (1), who isolated them from the speckled

trout and by ZoBell and Rittenberg (17), who found from one hundred to more than a thousand chitin digesters in each milliliter of the stomach contents of the squid.

There are few marine animals which do not ingest chitin if they come in contact with it. According to available information (8, 9, 10), however, the oyster does not take in chitin at any time. Accordingly, it is interesting to note that chitin-decomposing bacteria were found in the alimentary canal of this animal, also.

Decomposition of Limulus Shell in Natural Media

Having demonstrated the presence of chitin-decomposing bacteria in marine habitats, it was decided to follow the breakdown of a naturally-occurring chitinous material in several marine media. Accordingly, *Limulus* shells were scrubbed free of flesh, cut into strips approximately 3 × 8 cm., weighed (about 3 grams after drying overnight at 100–105° C.) and placed in marine sand, mud and sea water. Sand from the littoral region was scooped up, to a depth of 15 cm., and thoroughly mixed. Weighed strips of crab shell were placed in glass jars and covered with 200 grams of the sand. Likewise, strips of *Limulus* shell were covered with bottom mud collected in the Woods Hole harbor. Sea water, collected a few feet from the shore, was placed in bottles in 200 ml. volumes. Weighed strips of crab shell extended about 1 cm. above the water level. All cultures were kept in a dark cabinet at room temperature. Occasionally distilled water was added to the sand and mud cultures to prevent them from becoming dry.

These experiments were continued for 57 weeks. At stated intervals one culture from each of the three series (sand, mud, water) was examined. The crab shell was removed, weighed and checked for visible evidence of decomposition. Any changes in color and texture of the natural media were noted. The sand and the mud were analyzed for total organic carbon and nitrogen. The carbon was determined by Tiurin's modification (13) of Schollenberger's method (11). The nitrogen determinations were made by the usual Kjeldahl procedure. The results of the analyses are based upon the total dry sand or mud (dried overnight at 100–105° C.) not freed from the sea salt.

In sand, decomposition of the *Limulus* shell began at once. At the end of one year, when the experiment was discontinued, the shell had lost about three-fourths of its original weight (Fig. 1) and had been reduced to a small fraction of its former size. At the beginning of this experiment the sand contained 0.8 per cent carbon, and 0.05 per cent nitrogen, indicating that its organic content was relatively low. Al-

though a large amount of organic material was decomposed during the course of a year, there was no measurable increase in carbon and nitrogen in the sand. Presumably the compounds liberated from the crab shell were used in the metabolism of the bacteria.

When *Limulus* shell was placed in bottom mud, decomposition of the shell, as measured by decrease in weight, was detectable only after a period of about six weeks. Thereafter the shell decomposed fairly rapidly until at the end of one year it had lost a third of its weight (Fig. 1). The original mud was high in organic content. When brought into the laboratory it contained 2.4 per cent carbon and 0.17 per cent nitrogen. During the course of decomposition of the crab

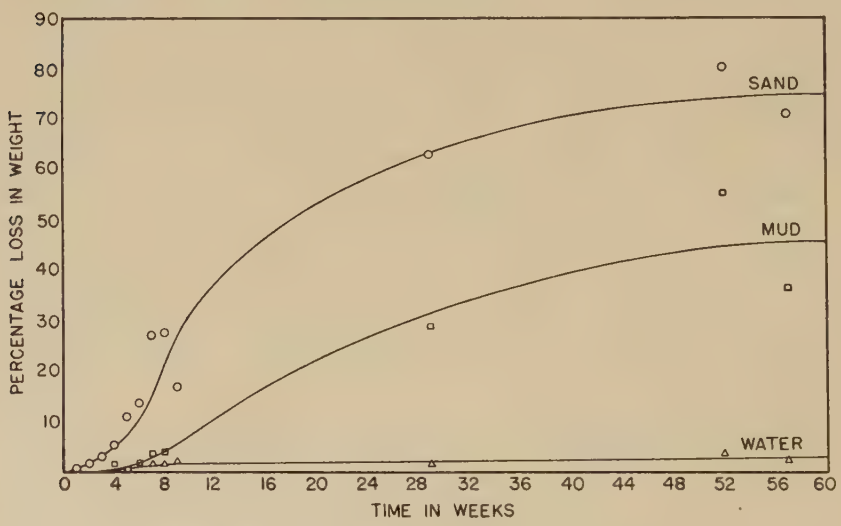

FIG. 1. Decomposition of horseshoe crab shell in natural marine media.

shell over a period of one year, the amount of carbon in the mud remained unchanged, while the nitrogen increased from 0.17 to 0.22 per cent.

In sea water there was only a very slight decrease in weight of the crab shell, even after a period of more than a year (Fig. 1). At the end of this time the shell was practically unchanged in appearance. This need not mean that chitin-decomposing bacteria were absent from the sea water, but only that under the experimental conditions there was no marked breakdown of the chitin in this medium, whereas in sand and in mud, under comparable conditions, the decomposition was pronounced. As far as laboratory experiments can show, chitin appears to be decomposed more slowly by marine bacteria than are most other structural organic materials.

During decomposition the shell underwent striking physical changes. Originally tough and leathery, it became soft and fragile as large areas were removed. Incipient decomposition was detected by using a binocular microscope, when the shell was observed to be "eaten" away in spots. In advanced stages of decomposition the shell was greatly reduced in size as well as in weight. In preparing purified chitin from *Limulus*, it was noted that continuous sheets of the purified material were obtained from all parts of the shell. It follows, therefore, that as the latter decomposed in these natural marine media, the chitin was digested along with the other compounds which make up the horseshoe crab shell.

The detailed characteristics of these bacteria are now being investigated. Preliminary tests indicate that approximately fifteen types of bacteria have been isolated. They are Gram negative, asporogenous, motile rods. Among the readily demonstrable products resulting from the decomposition of purified chitin by pure cultures of the bacteria are ammonia, reducing substances, and organic acids.

Summary

Chitin-decomposing bacteria were isolated from the following sources: marine sand, mud, water, decomposing horseshoe crabs, and the intestinal contents of *Venus mercenaria mercenaria*, *Ostrea virginica*, *Loligo pealeii pealeii*, *Ovalipes ocellatus ocellatus*, *Mustelus mustelus*, *Raia erinacea* and *Spheroides maculatus*.

Chitin-decomposing bacteria were found to be most abundant in marine sand, less abundant in mud, and present in small numbers in sea water.

Under experimental conditions, the decomposition of *Limulus* shell was relatively rapid in littoral sand, moderate in bottom mud, and negligible in sea water.

The writer is indebted to Dr. Selman A. Waksman for his interest and helpful suggestions.

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Contribution No. 237

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ANCHORING SHIPS ON THE HIGH SEAS*

By LIEUTENANT H. R. SEIWELL, *Sn-Res.*

Introduction

As a result of physical and chemical investigations of the sea conducted for more than half a century, the principal circulation features of the ocean basins are now believed to be generally known. Consequently, new methods for studying oceanic phenomena are being used which frequently require fundamental alterations in the customary field procedure of making observations at sea. For instance, to obtain continuous measurements of physical and chemical variations at fixed points in the sea, operations need to be carried out for periods of several days from a vessel anchored in the great depths of the ocean basins; and with modern precision instruments the data's value depends chiefly on maintaining the vessel in a relatively fixed position during observations. Measurements of oceanic phenomena from ships anchored on the high seas, although rare, are not new, and have been successfully carried out by at least six different research ships. Mooring ships in the great depths of the ocean basins, however, is still largely in an experimental stage. While actual demonstrations have solved the more general questions of technique, numerous specific problems for any individual vessel must be met under a variety of different, often difficult, conditions.

The two types of oceanographic measurements made from an anchored vessel differ in requirements of stability. Thus, observations on time variations of physical and chemical properties of the water (temperature, salinity, etc.) at a series of determined depths, measured from the physical sea surface along a fixed vertical, are not affected either by the usual pendular motions or by small amounts of drifting of the ship, and are more easily carried out. The procedure, as used on *Atlantis*, is to make repeated successive samplings of the water column (between surface and 1,200–1,400 meters) at 18 different depths with a similar number of reversing Nansen type water bottles, to each of which are attached two reversing thermometers. Entanglements of the hydrographic (with samplers attached) and anchor wires, due to the ship overriding its anchor, can be avoided with judicious care.

The second method, direct measurements of ocean currents, is more uncertain, since best results require the impossible situation of a completely immobile vessel. As a consequence, corrections based on analysis of the anchored ship's pendular movements and drift must be applied in analyzing the observations. It is difficult to produce ideal conditions for the direct measurement of ocean currents from a ship anchored on the high seas as, for instance, through the use of triple moorings, two well-spaced anchors forward and one sternward.[1]

Deep Sea Anchoring and Equipment of Oceanographic Research Ships

The first anchorings in deep water for scientific investigations of the ocean were made by Pillsbury on the *Blake* in 1888 and 1889. Thirty-nine stations (up to 166 hours duration) were completed off the American coast in the Gulf Stream, the depths of mooring extending to approximately 4,000 meters. The method and

* Contribution No. 237, Woods Hole Oceonographic Institution.

[1] Spiess, F. "Mooring of Ships in Deep Water," *Hydrographic Review*, Vol. IX, No. L. May, 1932.

technique employed (described by Pillsbury[2]) demonstrated the feasibility of anchoring a large ship in the open ocean, and subsequent improvements are primarily the result of refined equipment. However, it was not until 20 years later that deep-sea anchoring was again attempted, when Helland-Hansen carried out a series of current measurements in the North Atlantic on board the *Michael Sars*, and then later, between 1913 and 1924, successfully made a number of deep-sea anchorings,[3] to depths of approximately 4,000 meters, from the *Armauer Hansen*, a ship of only 57 gross tons. Further oceanographic measurements from ships moored on the high seas were undertaken by the German research ship *Meteor* (67 meters length, 1,180 tons displacement) during 1925–27 and 1937–38 in the North and South Atlantic; by the Dutch research ship *Willebrord Snellius* (62 meters length, 1,055 tons displacement) during 1929–30 in the waters of the Dutch East Indies; and by the American research ship *Atlantis* (43 meters length, 460 tons displacement) from 1936 to the present in the western North Atlantic and Caribbean Sea basins.

Descriptions of the anchoring equipment and technique on *Meteor* have been given by Spiess,[4] Defant,[5] and von Schubert.[6] The anchor cable was one piece (without splice, the ends of each wire in every strand being welded together) galvanized cast steel, composed of 7 wire strands (24 wires each) wound over a hemp core, 7,500 meters long. The cable was tapered, the circumference of the end shackled to the anchor being 3.6 centimeters, and that fastened to the cable reel 5 centimeters. The deep-sea anchor was a normal or Admiralty type, long shank and iron stock, weighing 100 kilograms; for mooring, this was backed by a second anchor, a "stockless bower" (Wasteneys Smith's patent) of the same weight, with a 50-meter wire pendant. The amount of cable reeled out, in general, amounted to about $1\frac{1}{3}$ times the depth of water. Between 1925 and 1927, 9 anchor stations (13 to 65 hours duration) were occupied by *Meteor*, in the Atlantic between 24°N. and 28°S. The greatest depth of anchoring was 5,489 meters at Station 147 (14°–57.2′S., 0°–06.6′W.), where 6,500 meters of cable with two anchors were used; the ship lay at anchor for 49 hours dragging 2.4 miles. For this deep anchoring Spiess notes the mean wind velocity of force 4 to 5, increased to force 7 and the sea to 6, and that the anchor cable carried away while weighing due to the vessel's pitching in a sea way.

The anchor gear on *Willebrord Snellius* was essentially identical with that of *Meteor*: 7,500 meters of tapered, kinkless steel cable with two mushroom anchors weighing 100 and 200 kilograms, respectively. For mooring the 100 kilogram mushroom was shackled to the second heavier anchor by 30 meters of cable, and then followed by 15 fathoms of chain weighing 165 kilograms. Later, after loss of the lighter anchor, the 200 kilogram mushroom was successfully used alone.[7] This vessel occupied seven deep-sea anchor stations (24 to 89 hours duration) in the waters of the Neth-

[2] Pillsbury, John Elliott. "The Gulf Stream," *Rept. U. S. Coast and Geodetic Survey*, Appendix 10, pp. 461–620. 1891.

[3] Helland-Hansen, Bjørn, "*Neue Forschungen im nördlichen Atlantischen Ocean*," *Zeitschrift der. Ges. f. Erdkunde zu Berlin*, 1911; and Helland-Hansen, Bjørn. "*Meeresforschung mit kleinen Forschungsschiffen*," *Zeitschrift der Ges. f. Erdkunde zu Berlin*, 1928.

[4] *Ibid.*

[5] Defant, Albert, "*Die Gezeiten und inneren Gezeitenwellen des Atlantischen Ozeans*," *Wiss. Ergeb. der Deutschen Altantischen Expedition "Meteor,"* 1925–1927. Vol. VII, Part I; and Defant, A., "*Bericht über den ersten Teil der Deutschen Nordatlantischen Expedition des Forschungs-und Vermessungsschiffes 'Meteor,' Februar bis Mai 1937.*" *Sitzungsberichten der Preussischen Akademie der Wissenschaften.* Phys.-math. Klasse 1937. XIX.

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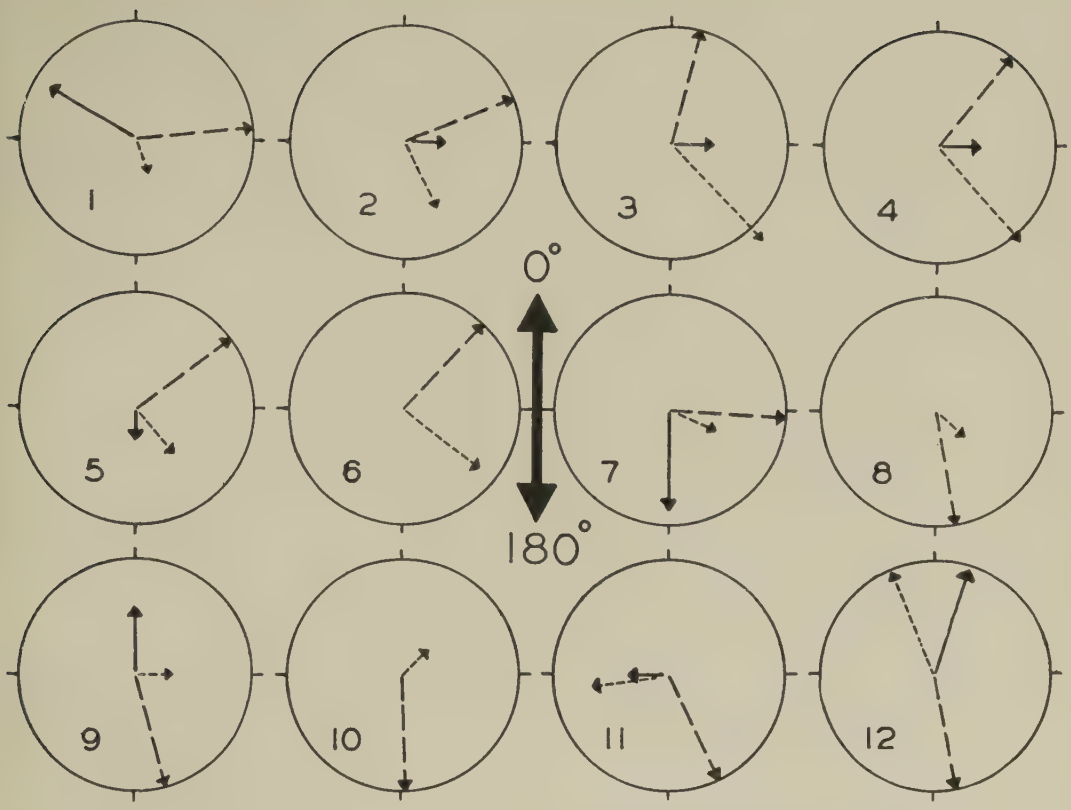

FIG. 1

General relationships between average ship's heading, average wind current directions (dashed arrow; 1 cm. = 1 Beaufort unit), and average ship's drift or anchor drag (solid arrow; 1 cm. = 0.2 naut), for 12 time intervals between position determinations, Oct. 9 to 14, 1939, *Atlantis* anchor Station 3703 (34°–56′N. 67°–09′W.). The 12 time intervals (+5 time zone) are:

1. Noon to 17^h–30^m, Oct. 9
2. 17^h–30^m to 05^h–05^m, Oct. 10
3. 05^h–05^m to noon
4. Noon to 17^h–30^m
5. 17^h–30^m to 05^h–07^m Oct. 11
6. 05^h–07^m to noon
7. Noon to 17^h–30^m
8. 17^h–30^m to 05^h–00^m, Oct. 12
9. 05^h–00^m to noon
10. Noon to noon, Oct. 13
11. Noon to 05^h–00^m, Oct. 14
12. 05^h–00^m to noon

erlands East Indies, at depths between 1,150 and 4,850 meters; at the deepest (Station 308a; 53 hours duration) 6,500 meters of anchor cable were lowered.

Deep-Sea Anchoring by "Atlantis"

The auxiliary steel ketch *Atlantis* (research vessel of the Woods Hole Oceanographic Institution), about 460 tons displacement, 142 feet length on deck and 29 foot beam, carries 7,200 square feet of canvas and is powered by a 280-horsepower Diesel engine. The latter also supplies power through a special dynamo to a heavy trawl winch in the lower hold that carries the anchoring cable. Specific arrangements were not made for deep-sea anchoring at the time of construction, 1930–31, but with the initiation of a deep-sea anchoring program several years later, available facilities were utilized to the extent that the only major acquisition was the construction of a steel gallows over the bow of the ship (see illustrations pages 1725–27) from which is suspended a 16-inch shiver to lead the anchor cable overboard. The gallows is bolted to the ship's hull and to take up extra strains two jury preventer stays are fastened between its head and the fittings of the jib backstay.

For deep-sea anchoring 29,500 feet (9,678 meters) of preformed, galvanized ½-inch steel rope, in one continuous length, is available. This cable, also used for deep-

TABLE I

SUMMARY: *Atlantis* DEEP SEA-ANCHOR STATIONS (MORE THAN 1,000 METERS DEPTH)

Station	Mean Position	G.M.T.[1]	Depth (meters)	(a) Cable length (b) % scope	(a) Anchoring[2] (b) Weighing	(a) Wind range (b) Mean	(a) Sea range (b) Mean	Drag	Remarks	Observation Time	No. Samplings	No. Temperature Samples[3]	Hydrographic Range	Wire Angle Mean[4]
3183	32°-06′N 64°-10′W	Oct. 14 (05^h-33′)-15 (15^h-34′) 1938	4,550	(a) 6222 (b) 36.75%	(a) 3^h-08′ (b) 2^h-10′	(a) 3-4 (b) 3-4	(a) 3-4 (b) 3-4	14th: 5^h-55′-12^h-00′=2.6 mi. 270°; 0.43 nauts		34^h-01′	24	360		
3245	25°-32′N 53°-46′W	Jan. 23 (02^h-54′)-24 (04^h-45′) 1939	4,865-5,000	(a) 6500 (b) 32.8%	(a) 2^h-30′ (b) 2^h-14′	(a) 1-2 (b) 1-2	(a) 1-2 (b) 1-2	05^h-50′-12^h-00′-4.4 mi. 155°; 0.71 nauts 12^h-00′-17^h-42′=3.5 mi. 210°; 0.61 nauts		25^h-51′	28	504	9°-23′-15°-36′	12°-47′
3296	14°-55′N 60°-18′W	Feb. 16 (01^h-06′)-17 (02^h-54′) 1939	3,266-3,386	(a) 5000 (b) 50.3%	(a) 2^h-05′ (b) 1^h-25′*	(a) 2-4 (b) 3	(a) 3-4 (b) 3	0	Anchor and 50-ft. Manila hemp lost; wire parted at shackle	25^h-48′	30	540	0°-16°-15′	12°-30′
3297	15°-38′N 66°-26′W	Feb. 27 (00^h-44′)-28 (02^h-02′) 1939	4,740-4,831	(a) 6400 (b) 33.7%	(a) 2^h-41′ (b) 2^h-15′	(a) 4-5 (b) 4	(a) 4-5 (b) 4	06^h-20′-12^h-00′=5.8 mi. 300°; 1.02 nauts 12^h-00′-19^h-00′=5.3 mi. 250°; 0.76 nauts		25^h-18′	29	522	13°-15′-20°-20′	16°-12′
3298	18°-10′N 75°-07′W	Mar. 3 (03^h-15′)-4 (07^h-13′) 1939	2,270-2,330	(a) 3500 (b) 52.2%	(a) 1^h-10′ (b) 0^h-30′*	(a) 0-3 (b) 1-2	(a) 0-3 (b) 1-2	0	Anchor and 1100 meters wire lost	27^h-58′	32	576	12°-35′-19°-14′	15°-03′
3300	19°-31′N 73°-26′W	Mar. 12 (15^h-41′)-13 (17^h-10′) 1939	1,190-1,400	(a) 1400 (b) 0.8%	(a) 0^h-39′ (b) 0^h-40′*	(a) 0-2 (b) 1-2	(a) 0-2 (b) 1-2	0	Anchor and 1200 meters wire lost	25^h-29′	31	558	11°-30′-17°50′-	15°-03′
3703	34°-56′N 67°-09′W	Oct. 9 (17^h-49′)-14 (21^h-37′) 1939	5,325	(a) 5948 (b) 11.7%	(a) 3^h-20′ (b) 1^h-36′*	(a) 0-4 (b) 1-2	(a) 0-3 (b) 1-2	Max: Oct. 14th, 05^h-00′-12^h-00′=4.1 mi.; 17° Rate=0.17-0.59 nauts Average=0.24 nauts	Anchor, weight, and 975 meters wire lost	123^h-48′	123	2213	0°-15°-00′	8°-52′

[1] Time interval between closing of first and final series of water samplers.

[2] *Gear lost while weighing.

[3] Approximately 15% of samples titrated for salinity.

[4] Based on computed depth of samplings; usually to depths of 250-300 meters

Courtesy Lieutenant H. R. Seiwell, Sn. Res.

DEEP SEA ANCHORING GEAR FOR THE *ATLANTIS*

Steel gallows erected on the bow for use in deep sea anchoring. (See article page 1733.)

Gallows rigged for deep anchoring in 5,325 meters of water. Steel anchor cable leads overboard through 16-inch shiver suspended from gallows.

Courtesy Lieutenant H. R. Seiwell, Sn. Res.

SHACKLING 250-POUND KEDGE ANCHOR TO A 50-FOOT, 3½-INCH MANILA PENDANT IMMEDIATELY BEFORE LOWERING

The kedge anchor is backed by a 300-pound block of cement which in turn is shackled to the steel cable.

Courtesy Lieutenant H. R. Sewell, Sn. Res.

LOWERING THE ANCHOR CABLE FROM THE BOAT DECK IN SIGHT OF RUNNING GEAR

Captain at winch control, First Officer recording. Anchor cable leads forward from dynamometer opposite winch control.

sea trawling, has its outer end of 500 feet composed of 6 strands (37 wires each) with hemp center, the next 10,000 feet is of 6 strands (19 wires each) with hemp center, and the final 19,000 feet identical except for a wire rope center. The extra pliability of the outer 500 meters has not withstood kinking, with subsequent breaking and loss of gear. From the winch control on deck, anchoring operations are conducted in full sight of all running gear (see illustrations). Ordinary iron stock kedge anchors weighing between 400 and 250 pounds have generally been used; at Station 3703 the lighter anchor was backed by a 300-pound block of cement to which it was shackled by a 50-foot, $3\frac{1}{2}$-inch Manila hemp pendant.

During the 7 *Atlantis* deep-sea anchorings, in depths of more than 1,000 meters (Table 1), 4 anchors and 3,100 meters of steel cable have been lost. In all cases except one (Station 3300), loss of gear resulted from the kinked steel cable breaking on weighing. At Station 3300 (in Gonave Gulf) the 500-pound anchor resisted all attempts to break free of the bottom and the steel cable broke at the dynamometer on deck; the wire would probably have been saved by use of a lighter anchor or by a weakened pendant shackled between anchor and steel cable. It is obvious that the use of "kinkless" cable, at least in part, is highly desirable, although this, in itself, is no guarantee against loss of gear. Since it appears that kinking occurs in that part of the cable which at some time or other during anchoring lies on the bottom, it is desirable to lower as little cable in excess of depth as is needed to prevent excessive drift of the ship. In general, an amount of cable about 15 per cent in excess of the depth appears to be adequate, although somewhat more may be required to reduce drag when anchored in strong currents or in winds above force 5. Thus, judging from *Atlantis* experience, for wind velocities up to force 5 variations in scope of the anchor cable of between 12 and 34 per cent appear to have little effect on the amount of drag. For instance, at Station 3297 (4,831 meters), with anchor cable lowered 33.7 per cent in excess of depth, and maximum wind velocity of force 5, the vessel's drag averaged 1.02 nautical miles per hour for nearly 6 hours; whereas at Station 3703 (5,325 meters), with the anchor cable only 11.7 per cent in excess of depth, and a maximum wind of force 4, the maximum computed drag averaged 0.59 nautical miles per hour. Drag at this latter station was even less than that at Station 3245 (0.71 nautical miles per hour) where cable length was 32.8 per cent in excess of depth and where surface wind velocities were only force 2. Effects of surface layer currents at these stations are unknown, but were not at any time much in excess of $\frac{1}{2}$ naut.

Accurate knowledge of the ship's drift and of its pendular movements is significant for reduction of the scientific observations, particularly when current measurements are undertaken. Computation of the ship's drift because of the anchor dragging (Table 1) is dependent on astronomical observations; in general, three satisfactory positions are available each day. The morning and evening position polygons are based on 3 to 5 position lines determined from altitudes of fixed stars or planets, and the noon position is based on several hour angle measurements of the sun during forenoon and afternoon combined with the meridian altitude. Accuracy of astronomically determined positions to ± 1 mile, using the usual instruments, tables, and methods, was generally accepted, and, in computations of drag, position differences of one minute of arc or less were not considered significant. The maximum drag computed for any station was at an average rate of 1.02 nautical miles per hour. In general, anchor drag is greatest at the beginning, diminishing as the anchor apparently obtains a better grip in the bottom; at the three shallowest

(1,190–3,386 meters) *Atlantis* anchorings, in spite of wind velocities up to force 4, the drag was practically nil.

Detailed consideration of the ship's drift (drag of anchor) for the 5 days it lay at anchor at Station 3703, during intervals between morning, noon, and evening positions, brings out that apparently, except for three periods (05^h–07^m to noon, Oct. 11; 17^h–30^m, Oct. 11 to 05^h–00^m, Oct. 12; and noon, Oct. 12 to noon, Oct. 13) the vessel dragged its anchor on an average between 0.17 and 0.59 nautical miles per hour (Table 1); the maximums being at the beginning (0.53 naut) with wind force 1, and, at the end (0.59 naut) with wind force 3. Variations in ship's drift while at anchor, besides resulting from combined effects of wind and water currents, are apparently caused by the anchor's alternate gripping and breaking from the bottom. The general relationship between wind current directions, ship's heading, and drift is brought out for the 12 intervals (between position determinations) in Fig. 1 (page 1735). The drift of the ship was not at any time in the same direction as the wind current; for instance, between noon October 9 and 05^h October 12 while the air current moved in a relatively steady direction (between average values of 113° and 158°) the ship drifted between 46° and 60° to the left and between 40° and 143° to the right. Still later, as the wind direction became more variable, the vessel drifted between 90° to the left and 40° to the right of the average direction of air flow.

The relation between ship's heading and its direction of drift while at anchor was likewise variable; average values for the 12 intervals (see Fig. 1) show that two thirds of the time the drift was between 22° and 127° to the right (clockwise) of the heading and one third of the time between 84° and 164° to the left (counterclockwise) of the heading. Data on the ship's swing are obtained by frequent observations of the ship's heading (taken every 2 hours at Station 3703); the average angular range between ship's heading and direction of the wind current was between 20° and 169° with ship heading to the left (wind blowing on port side) and between 39° and 133° with ship heading to the right (wind blowing on starboard side) of the wind current direction. The average angular swing of the ship per 2-hour intervals for the 5 days was 20°, varying between 0° and a maximum of 125°; for wind velocities less than force 3 the average angular swing per 2-hour intervals was 21° and for winds of force 3 it was 15°.

From the standpoint of obtaining measurements on time variations of the properties of sea water (temperature, etc.) along a fixed vertical in the ocean space, the anchoring arrangements on *Atlantis* are adequate. The swing of the vessel does not interfere with this type of observation, and the small amount of drift (anchor drag) and the apparently almost complete absence of anchor overriding, permit, even in regions of strongest horizontal gradients, satisfactory results while lying at anchor on the high seas for a week or more. On the other hand, while motions of the above magnitudes would invalidate results of direct current measurements, a recent mooring in the Gulf Stream has shown that pendular motions and drift are reduced to a minimum in a strong gradient current. Thus, during February 12 to 14, while *Atlantis* was moored with mushroom anchor at approximately 800 meters depth in the axis of the Gulf Stream, off Cape Canaveral (not entered in Table 1), current measurements undertaken between surface and 100 meters depth were satisfactory. Not only was there an apparently complete absence of drift, but also the swing of the ship was only 2° to 5° per hour.

Results of Observations from an Anchored Ship

(*a*) *Time variations of physical properties.*—The desirability of obtaining measurements from a ship lying at anchor on

the high sea arises from the relatively recent discovery of internal waves—a phenomenon of vertical oscillations of the water particles which causes time variations of chemical and physical properties at fixed depths in the sea. These investigations have not only theoretical significance, but also supply critical information for the interpretation of practical oceanographical questions, as, for instance, in estimating significance of circulation patterns derived from distributions of the basic properties of temperature and salinity. Because vertical oscillations of the water will usually prevent representing average conditions in the sea based on single samplings along isolated verticals, the distributions of mass and pressure as usually computed for an oceanic area, and in turn used for derivation of horizontal circulation patterns, may be of doubtful significance, particularly in regions of not too strongly developed horizontal gradients (as in the Western Sargasso Sea). Hence, to control the significance of computed dynamic patterns, such as may be accomplished by knowledge of ratios of time changes at fixed points to computed horizontal changes of the properties involved, repeated observations for 25 hours or more are undertaken along selected fixed verticals in the area, simultaneously with its survey.

As an example of the time change in physical properties at fixed points in the sea, we briefly consider certain results observed during a 26-hour period of repeated sampling at Station 3245 (Table 2), and

Table 2

Depth (Meters)	*Temperature*		*26-Hour Temperature Range*
	Maximum	*Minimum*	
100	22.47°	21.16°	1.31°
150	21.08°	18.83°	2.25°
200	18.30°	17.98°	0.32°
500	15.31°	14.74°	0.57°
800	9.30°	8.64°	0.66°
1000	6.79°	6.29°	0.50°

Table 3

Depth	*Temperature Range June 22*	*Temperature Range June 27*
50	1.55°	0.90°
200	0.10°	0.08°
500	1.09°	0.34°
800	2.50°	1.12°
1000	1.43°	0.39°
1200	0.40°	0.23°

from a 14-day period at Station 3091 (Table 3). Both stations are located in the western basin of the North Atlantic (Table 1). At the former station (3245) the amount of temperature variation at fixed depths during the 26-hour period ranged from 0.32° in the nearly homogeneous part of the water column to 2.25° in the most strongly stratified part; a result of vertical displacements of the water particles of 15 to 56 meters. This demonstrates that single samplings of the water column will not represent average conditions in the region concerned. Moreover, a region cannot be characterized for extended periods on the basis of a single day's repeated observations, since data show that magnitude of vertical displacements of the water particles, and consequently the accompanying time variations of temperature at fixed depths, change from day to day. In this respect the effects of both quiet and disturbed days are brought out by comparison of 24-hour temperature ranges at selected depths on two different days, taken from the 14-day series of continuous sampling at Station 3091, tabulated in Table 3. The vertical displacements of the water column bringing about these 24-hourly temperature variations at fixed depths were on the average three times as great on June 22 as on June 27,[8] five days later.

[8] See also H. R. Seiwell, "Short Period Vertical Oscillations in the Western Basin of the North Atlantic"; *Papers in Physical Oceanography and Meteorology*, Vol. V, No. 2. "The Effect of Short Period Variations of Temperature and Salinity on Calculations in Dynamic Oceanography," *ibid.*, Vol. VII, No. 3. "Daily

(*b*) *Short time variations in surface layer velocity of the Gulf Stream.*—As a result of surface current observations with a small taffrail log, read approximately every 15 minutes, between 10^h February 12 and 04^h February 14, 1940 (G.C.T.), while *Atlantis* was anchored during a period of light winds (0–2 Beaufort) in the Gulf Stream axis off Cape Canaveral (Station

TABLE 4

Date	*G. C. Time*	*Velocity-Nauts*
2/12/40	11:00–12:00	3.70
	14:00–15:00	3.28
	17:00–18:00	3.02
	20:00–21:00	2.97
	23:00–24:00	2.97
2/13/40	02:00–03:00	2.72
	05:00–06:00	2.47
	08:00–09:00	2.45
	11:00–12:00	2.48
	14:00–15:00	2.83
	17:00–18:00	3.30
	20:00–21:00	1.52
	23:00–24:00	1.35
2/14/40	02:00–03:00	1.50

3777, 28°-55′ N., 79°-36′ W.), average surface velocities as computed for one-hour intervals (Table 4) ranged between 3.70 and 1.35 nautical miles per hour. The average surface velocity for the entire 42 hours was 2.60 nautical miles per hour (134 cms/sec) and the two velocity maximums were separated by a 30-hour and the two minimums by a 12.5-hour interval. These observations are significant in that they show large variability in surface velocity at fixed points in the Gulf Stream, and questions concerning the depth and extent to which the main body of the Gulf Stream is affected are of added importance. Comparisons of simultaneous surface and subsurface readings at depths of 25 and 50 meters (taken with an Ekman current meter) indicate that although velocity variations are to some extent re-

TABLE 5

G. C. T.	*Velocity: cms./sec.*		
	0 m.	*25 m.*	*50 m.*
13th 16^h 18^m	161	146	
16^h 52^m	166	137	
18^h 03^m	172		122
20^h 50^m	71	110	
22^h 07^m	72	107	
23^h 20^m	65		112
14th 00^h 20^m	63	100	
03^h 46^m	94		107

flected downward they appear to be rapidly damped. Thus, simultaneous surface and 25 meter readings (Table 5) show that while the former diminished in velocity from 166 to 63 cms/sec, the 25-meter velocity changed from 146 to 100 cms/sec; still deeper, as brought out by comparison of surface and 50-meter levels, the velocity of the former dropped from 172 to 65 cms/sec while the latter remained nearly constant, decreasing from 122 to 107 cms/sec. Hence, considering the great thickness of this current, it is unlikely that the total transport of water is significantly affected by short period variations of this type. Since the observations apparently reveal the usual state of the surface layer of the Gulf Stream they are of considerable interest and may serve to clarify some of the curious sailing phenomena attributed by navigators to the Gulf Stream.

Temperature Variations in the Western North Atlantic," *Journal du Conseil*, Vol. XIV, No. 3.

Contribution No. 239

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19.

Eastern Pacific Expeditions of the New York Zoological Society. XX. Medusae of the Templeton Crocker and Eastern Pacific *Zaca* Expeditions, 1936-1938.[1]

Henry B. Bigelow

Museum of Comparative Zoology, Harvard University.

(Text-figures 1-20).

[This is the twentieth of a series of papers dealing with the collections of the Eastern Pacific Expeditions of the New York Zoological Society made under the direction of William Beebe. The present paper is concerned with specimens taken on the Templeton Crocker (1936) and Eastern Pacific *Zaca* (1937-1938) Expeditions. For data on localities, dates, nets, etc., refer to *Zoologica*, Vol. XXII, No. 2, pp. 33-46, and Vol. XXIII, No. 14, pp. 287-298.]

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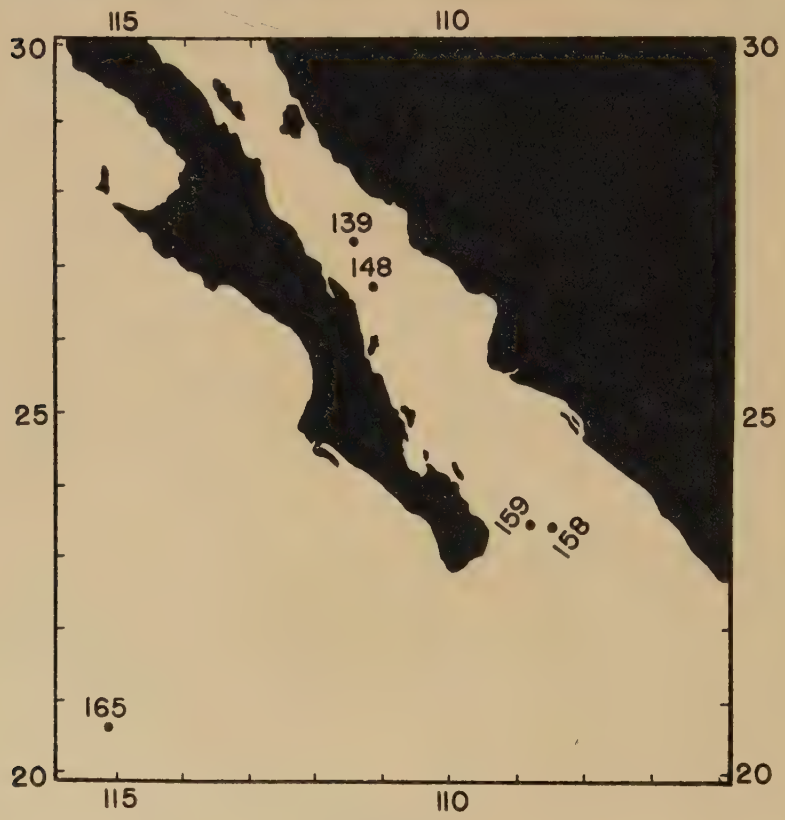
[1] Contribution No. 601, Department of Tropical Research, New York Zoological Society. Contribution No. 239 of the Woods Hole Oceanographic Institution.

Introduction.

The medusae described in the following pages were collected by Dr. William Beebe on Mr. Templeton Crocker's Yacht *Zaca,* off Lower California and in the Gulf of California in April-May, 1936, and along the Pacific coast of Central America from Costa Rica to Panama in February-April, 1938. For data of the stations where medusae were taken on the first of these cruises (Stas. 139-165), see Beebe (1937); for those of the second cruise (Stas. 210-234), Beebe (1938).

The locations of the stations are shown on Text-figs. 1 and 2.



Text-fig. 1.
Locations of stations 139-158, April, 1936.

Hydromedusae.

Anthomedusae.

Pandeidae.

Stomotoca.

Differences of opinion still exist as to whether the pandeids with only two large opposed tentacles, but many rudimentary tentacles, represent two genera, one with gelatinous peduncle (*Stomotoca*), the other without (*Amphinema*), or whether they properly form but a single genus, to which the name *Stomotoca* must be applied, on the grounds of priority. The latter

Text-fig. 2.
Locations of stations 210-234, February-April, 1938.

viewpoint has recently been adopted by Uchida (1927) and by Ling (1937), following Mayer (1910). To Hartlaub (1914), however, among others, to Russell (1938), and to me (1909, 1918), the presence or absence of a peduncle has seemed a character of generic importance, and is so considered here.

Stomotoca pterophylla Haeckel.

Stomotoca pterophylla, Haeckel, 1879, p. 52, Pl. 4, Fig. 10. For subsequent references and discussions, see Bigelow, 1918, p. 372; Ranson, 1936, p. 63.

Material: Sta. 229, surface, 1 specimen about 20 mm. in diameter: Sta. 231, surface, 1 specimen about 22 mm. in diameter, both in moderately good condition.

Comparison of series from the Florida-Bahaman region and from the Eastern Tropical Pacific has failed to reveal any significant difference between the Pacific *divisa* and the Atlantic *pterophylla* (Bigelow, 1918, p. 370); and this conclusion the present examples corroborate, for they agree in all significant respects with Maas' (1897) account of "*S. divisa*" from the Gulf of Panama, and with the *Albatross* series reported by me under that name

from the vicinity of the Galápagos and from the West coast of Mexico (Bigelow, 1909).

Records for the compound species in the Pacific are confined to the vicinity of the Galápagos, and along the west coast of America from southern Mexico to Colombia. In the Atlantic, however, its range appears to be more extensive, for it has been taken not only near Florida and the Bahamas in the western side (Haeckel, 1879; Mayer, 1910; Bigelow, 1918), but also in the central basin (Ranson, 1936).[2]

Leuckartiara.

Leuckartiara zacae sp. nov.

Text-figs. 3-5.

Material: Sta. 227, 910-0 meters, one specimen about 21 mm. high by 18 mm. in diameter, somewhat shrivelled in preservation, but otherwise in fair condition.

In 1916, Browne described, from the Indian Ocean, an interesting new pandeid (*Leuckartiara gardineri*), the generic identity of which was established by the structure of its gonads, but which differed from all known representatives of *Leuckartiara* in the presence of exumbral nematocyst-ribs extending upward over the surface of the bell from the bases of the tentacles. This character it shares with *Pandea conica* and with *Eutiara mayeri,* the gonads of which are, however, very different.

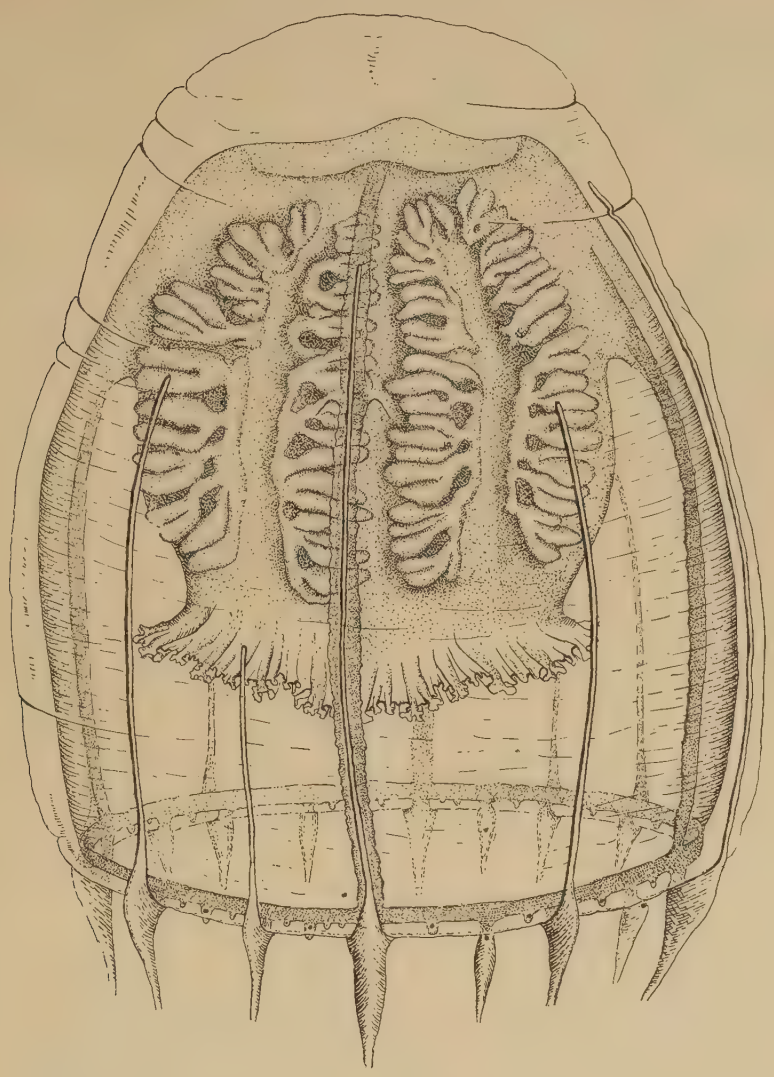
The present specimen, similarly referable to *Leuckartiara* by its gonads, recalls *gardineri* in the presence of exumbral ribs. And (so far as can be judged in optical section) these ribs, like those of *gardineri* and of *Eutiara mayeri* (Bigelow, 1918, p. 375), are canalar extensions of the tentacular bases, whereas in *Pandea conica,* Hartlaub (1913, p. 336) describes them as simply thickenings of the ectoderm. It differs, however, from *gardineri* in the following respects:

1. *Number of tentacles*: In the unique specimen of *gardineri,* there were only four large (perradial) tentacles and in addition about 24 rudimentary knobs, some with filaments, but others lacking the latter. And since the gonads contained fairly well-advanced ova, it seems probable that four is the final number of large tentacles in that form. In the *Zaca* specimen, however, there are (besides the four perradials) two or three other well-developed tentacles of different sizes per quadrant (a total of fifteen), each with corresponding exumbral rib, and also 1-3 rudimentary knobs (lacking filaments) between every two tentacles (Text-fig. 3).

2. *Number and length of exumbral ribs*: In Browne's specimen of *gardineri* there were four of these, one opposite each perradial tentacle and extending nearly to the apex of the bell. In the present example, in addition to the four perradials, there are 2, 1, 1 and 1 others in the different quadrants, or a total of nine, each connected with a tentacle. And while four of the smaller tentacles lack them, exumbral ribs might later have developed in connection with these also. On the other hand, even the perradial ribs reach up only about ⅔ of the height of the bell, i.e., to about the level where the radial canals arise from the manubrial wall, while the others reach only to about the mid-level of the bell.

3. *Gonads*: These are considerably more complex than in *gardineri,* there being 8-12 primary folds, which bifurcate or trifurcate in each adradial series, as against 4-5 primary folds only—each bifid—per adradial series in *gardineri.* In *gardineri,* furthermore, the adradial series are united in

[2] Ranson (1936, p. 64) states that the Monaco specimen was collected "au sud des Açores." But the position of the station in question (Monaco, Station 2115) is given as Lat. 31° 42′ N., long. 42° 40′ W., or roughly midway between the Azores and Bermuda.

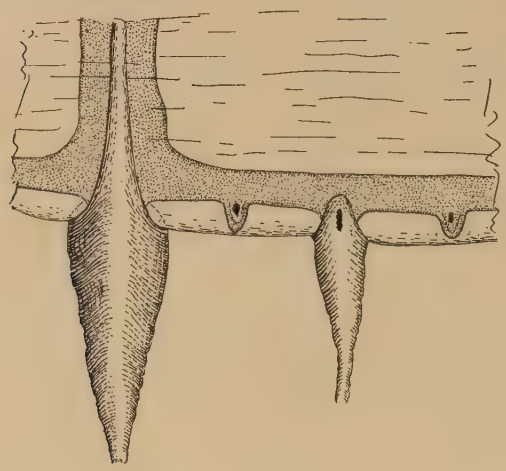


Text-fig. 3.
Leuckartiara zacae, sp. nov., type specimen, slightly restored.

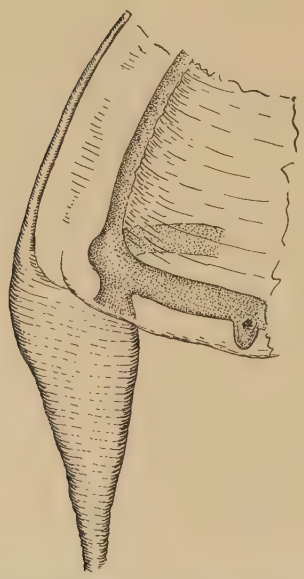
each quadrant, by a transverse fold at about the mid-level of the manubrium (Browne, 1918, Pl. 39, Fig. 4), but this commissure is evident in one quadrant only of the *Zaca* specimen, suggesting that its presence represents a transitory stage in development. The specimen is apparently a male; at least no ova are visible in surface view.

Evaluation of these differences depends on whether the new-found specimen represents merely an advanced stage in the growth of a known species (all the differences being of a progressive sort), or whether it is a distinct species which, in its growth, passes through a stage in which it closely resembles the known form, but which attains to a greater degree of morphological complexity before reaching maturity. In the present instance, the available bases for decision are conflicting, for while the *Zaca*

specimen is about six times as large as the type of *gardineri* (suggesting an advanced stage in growth), the localities of capture for the two are on opposite sides of the globe. And since it seems important to emphasize the differences rather than to minimize them, so that the matter will be more searchingly examined by whomever is lucky enough to obtain additional specimens, a new specific name is proposed for the medusa under discussion here.



Text-fig. 4.
Leuckartiara zacae, sp. nov., margin with large and small tentacles, camera drawing, about × 14.



Text-fig. 5.
Leuckartiara zacae, sp. nov., lateral view of radial tentacle with nematocyst rib, about × 15.

Further points worth notice are that the tentacular bulbs are laterally flattened, clasping the exumbrella (as is usual in this genus), and that the tentacular knobs, as well as such of the fully formed tentacles as still lack exumbral prolongations, bear pigment spots on their abaxial sides. But the spots ("ocelli") are lacking on the tentacles in connection with which exumbral ribs have developed—apparently they are lost when the latter structures appear. The edges of the notably broad radial canals are slightly wavy; those of the ring canal smooth.

The ocelli are brick red, the manubrium and tentacular bulbs a pale salmon-color after preservation, which suggests a more brilliant reddish or pinkish hue in life.

Neoturris.

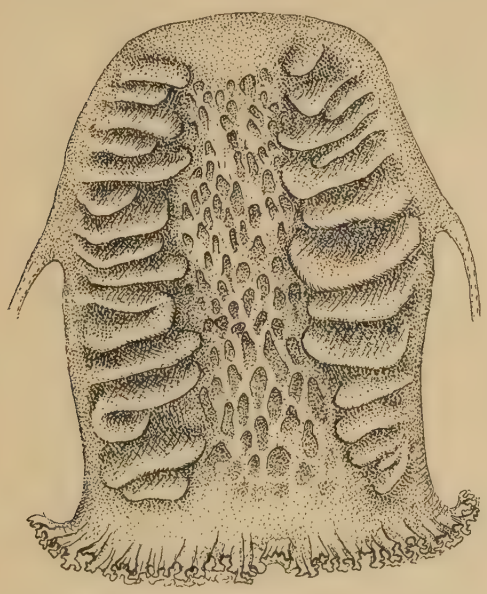
Neoturris crockeri sp. nov.

(Text-figs. 6-10).

Material: Sta. 234, 910-0 meters, 1 fragmentary specimen about 28 mm. high by about 32 mm. in diameter.

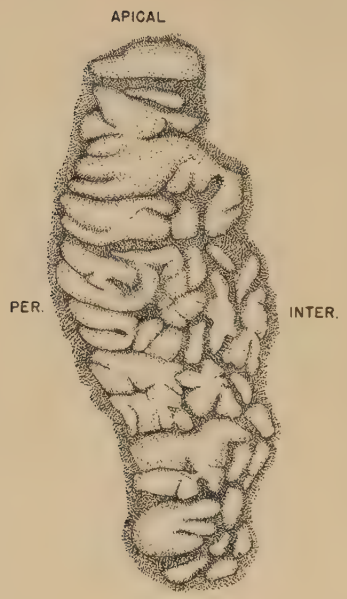
The unique example is so badly battered that reconstruction of the general form of the bell can be only tentative, further than that it is thin-walled throughout, without apical thickening, and apparently slightly broader than high. Fortunately, however, (though now in fragments) it still shows the chief anatomical characters.

At first glance, the specimen might easily be mistaken for a *Pandea rubra,* thanks to its dark chocolate-red pigmentation (see below). However, the structure of the gonads is quite different, being clearly of the *"Neoturris"* type as defined by Hartlaub (1914). More precisely, each perradial belt is flanked, on either hand, by a series of transverse folds of various sizes (Text-fig. 6). As is typical of *Neoturris,* the sexual folds are not connected one with another at their interradial ends, but are entirely independent. But the interradial zone of the manubrial wall, between each two series of folds, is occupied by a series of small irregular ridges—primarily longitudinal—alternating with recesses. Comparison of Text-fig. 6 with Hartlaub's (1914, p. 35, Fig. 273) picture of the manubrium of *N. pileata* will show the essential similarity. However, while the adradial folds are simple in one of the quadrants (Text-fig. 6), in another adjacent (Text-fig. 7) they are so complexly split and cross-furrowed that it is impossible either to distinguish between primary folds and secondary, or even, in the extreme case, to distinguish sharply where adradial folds give place to interradial mesh-work. Locally, then, the *"Neoturris"* state grades into the *"Pandea"* state. Nowhere, however, does it grade into the *"Leuckartiara"* state, i.e., that in



Text-fig. 6.

Neoturris crockeri, sp. nov., interradial view of one quadrant of manubrium to show gonads, somewhat restored.



Text-fig. 7.

Neoturris crockeri, sp. nov., adradial series of sexual folds in quadrant adjacent to that shown in Text-fig. 6. Camera drawing.

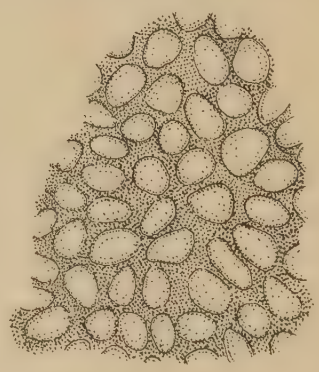
which the interradial extremes of the transverse adradial folds are connected. The specimen is a female, the sex folds packed with large eggs (Text-fig. 8)—and scattered eggs are to be seen in the interradial belts, as well. It is interesting, as an example of a fate that no doubt causes an appreciable destruction of medusan eggs, that in the present case a considerable number are to be seen within the radial canals.

The relationship of radial canals to manubrium is of the type characteristic of the more complexly organized pandeids (*Neoturris, Pandea, Leuckartiara, Catablema*), for the so-called "mesenteries" are so well developed (Text-fig. 6) that the canals depart from the manubrium at about the mid-level of the latter. Above this level, consequently, the bell cavity is subdivided into four extensive pockets by the lines of attachment between the manubrium and subumbrella.

The canals themselves are broad, flat (as usual in this family), their edges nearly smooth—or at most but slightly irregular. And this applies equally to the margin of the ring canal. The manubrium occupies the greater part of the bell cavity, hanging in its present state about to the level of the bell opening. The lips are complexly crenulated, much as in *Pandea rubra*.

Text-fig. 8.

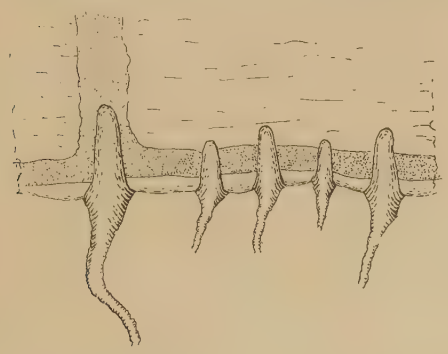
Neoturris crockeri, sp. nov., portion of one of the sexual folds packed with ova, camera drawing, × 60.



There are 38 tentacles, the numbers in successive quadrants being 10, 9, 9, 10, of various sizes (Text-fig. 9). Presumably this would have been the final number in this particular specimen, for there are no additional rudiments or knobs. The tentacle bases, broadly triangular in side view (Text-fig. 10), and laterally compressed, clasp the exumbrella, as is so commonly the case in this family, and taper gradually to slender filaments.

There is no trace of exumbral ridges connected with the tentacles. And since the surface of part, at least, of the bell is in fair condition, there is no reason to suppose that such structures were present in life, but had been destroyed. Neither are any ocelli to be seen.

The most interesting feature of this specimen is its bathypelagic coloration, the manubrium as a whole being of a dense reddish-chocolate hue, paling at the lip, and with the opaque white eggs showing through the overlying, pigmented ectoderm, much as do the larger eggs of the Narcomedusa, *Aeginura grimaldii.* The bases of the tentacles and a narrow peripheral belt of the subumbrella are sparsely pigmented with the same hue, the pigment granules in the latter cases so large and loosely spaced as to be individually visible under low magnification. The remainder of the subumbrella is faintly tinged, though without visible granules.



Text-fig. 9.

Neoturris crockeri, sp. nov., segment of margin to show the tentacles of different sizes, about × 7.5.

Superficially, as noted above, this specimen most resembles *Pandea rubra* among known pandeids. However, the tentacles are considerably more numerous, the maximum yet recorded for a considerably larger specimen of *rubra* being only 20 (Bigelow, 1938, p. 107). More important, the structure of the gonads proves that the resemblance to *Pandea rubra* is only super-

Text-fig. 10.

Neoturris crockeri, sp. nov., lateral view of one of the medium-sized tentacles.

ficial and that we are actually dealing with a *Neoturris*. However, it differs from all known pandeids in which the gonads are definitely known to be of the "*Neoturris*" type, not only in its peculiar pigmentation, but also in the facts that the radial canals are smooth-edged, and that the tentacular organs, large or small, are so few in number and consequently so widely spaced. A new species seems therefore necessary for its reception.

The depth of capture of the type (and so far only known) specimen (910-0) argues, as does its color, that it is a member of the bathyplankton.

Calycopsis.

Up to the present time, eleven supposed species have been referred to this genus or to *Sibogita,* now generally considered synonymous with it. The necessity of decision as to the status of its representative in the *Zaca* collection makes this an opportune time to summarize the features by which the several named members of the genus have been separated one from another. Critical revision (depending on the evaluation of variability) must, however, await the accumulation of larger study series.

One of the species, *birulai* Linko (1913), can be omitted from the discussion, on the ground that it does not belong to this genus, but is more closely allied to *Eumedusa similis* (Bigelow, 1920). It may, in fact, prove identical with the latter, in which case Linko's specific name would take precedence.

For the remaining members of *Calycopsis,* the following characters have been chiefly emphasized as specific: 1, number of tentacles and canals and their interrelationship; 2, arrangement of centripetal canals and the degree to which these finally fuse either with one another, with the radials, or with the base of the manubrium; 3, morphology of the gonads; 4, presence or absence of labial nematocyst knobs; 5, whether or not the radial canals are dilated at their points of emergence from the manubrium to form so-called "mesenteries"; 6, presence or absence of gelatinous exumbral papillae on the marginal lobes of the bell; and 7, presence or absence of a funnel-shaped apical exumbral depression. Among these characters, the presence of an apical depression in *typa,* of labial nettle knobs in *nematophora,* and of prominent papillae on the exumbral surfaces of the marginal lobes in *papillata,* in *valdiviae,* and in at least one of the specimens in the collection of the German South Polar Expedition (taken near the Cape Verdes), that were recorded by Vanhöffen (1912) as "*typa,*" contrasted with their absence elsewhere, is strictly alternative. The presence or absence of subumbral muscle bands along the radii of the tentacles, and of pigment spots at the bases of the tentacles, also appears to be alternative at least between certain of the named forms. Similarly, the conformation of the gonads is of two rather sharply opposed types, for while in *borchgrevinki* (at least in the male), the sex products develop in pockets of the manubrial wall, and open to the exterior by small pores (Browne, 1910; Vanhöffen, 1911, p. 216, Fig. 10a; Mackintosh, 1934), the gonads of all other known members of the genus form double rows of transverse folds, occupying the interradial sectors of the manubrium, the minor divergences being that in *nematophora,* small irregular folds occur between the chief series, and that in *typa,* the gonads bear egg-shaped swellings, scattered here and there (Bigelow, 1909a, Figs. 1, 2).

Other characters are less sharply discontinuous. Thus, *chuni* with 36-27 canals, *geometrica* with 32-22, *typa* with 21-16, and *nematophora* with 18-16 form a continuous series. In *valdiviae,* however, the number of canals recorded (60) is some 20 greater than in any other known *Calycopsis;* in *bigelowi* and in *simplex,* it may be permanently smaller (8). In *simulans* and in *papillata,* the number (12 in each case) appears to be determinate,

probably also in *borchgrevinki* (16), whereas in most, at least, of the other supposed species it is variable. In *simulans* and *papillata,* furthermore, the centripetal canals are all adradial, whereas in all other named forms in which the metameral arrangement has been determined, there is an interradial canal in each quadrant with or without adradials according to the number of centripetals peculiar to the particular species in question. In this respect, *typa* is especially unstable for there may be 2, 3, or 4 canals in adjoining quadrants (Bigelow, 1909a), beside the interradial member. Ordinarily the centripetals arise singly from the ring canal. In *typa,* however, they may exceptionally arise in pairs (Bigelow, 1909a, Fig. 7), while in *chuni* they may be either single or in groups of two or three (Vanhöffen, 1911, p. 218, Pl. 22, Fig. 8).

In previous discussions of the genus, much emphasis has been laid on the endings of the centripetal canals, i.e., whether permanently blind, or whether finally fused with the radial canals, or with the cruciform base of the manubrium. In *bigelowi,* in *simplex,* and in such of the specimens recorded as *typa* as seem properly to have belonged to that species, the canals are described as ending blindly—in the latter case even in a specimen 37 mm. high with large ova (Bigelow, 1909a, p. 290). In *simulans* and *valdiviae* some at least join the base of the manubrium, but others (by present indications) may remain permanently blind, which according to Browne (1910, p. 17) also applies to *borchgrevinki.* In *nematophora* all come finally to join the base of the manubrium—a junction interpretable in some cases as with a radial canal at its point of origin from the manubrium (Bigelow, 1913, Pl. 3, Fig. 24). In *papillata* they all end blindly in medium-sized specimens, but in the largest (27 mm. high, with eggs), two were still blind, "but of the remaining six, three have joined the cruciform base of the manubrium; two join radial canals close to their bases, and one joins a radial canal at a considerable distance from the manubrium" (Bigelow, 1918, p. 280, Pl. 2, Fig. 1). This specimen thus bridges the gap between the foregoing group and *geometrica,* in which all the centripetals unite with the radials at different levels.

The numbers of tentacles in the different members of *Calycopsis* overlap to a greater degree than do the numbers of canals, the total range (60-8) being practically covered by three species, *nematophora* (57-30), *typa* (30-16), and *borchgrevinki* (8-16). Recorded numbers of tentacles for the other supposed species are: *valdiviae,* about 60; *bigelowi,* 48; *chuni,* 16-17; *geometrica,* 16-22; *simulans,* 12-18; *papillata,* 12; *simplex,* 8.

As appears from the foregoing, the canals and tentacles may be equal in number (a tentacle opposite every canal); they may be either equal in number or the tentacles the more numerous (*simulans*); the tentacles may be characteristically the more numerous (*borchgrevinki, bigelowi, nematophora, typa*); or the canals the more numerous (*geometrica, chuni*).

In *typa,* it appears that the tentacles develop before the corresponding canals appear; apparently also in *nematomorpha,* hence this is likely the general rule, except in forms in which the final number of canals is greater than that of the tentacles.

Taxonomic evaluation of labial knobs and of gonad-structure presents no difficulty, for these both appear of full specific import. Thus, *nematomorpha* is set apart from all other members of the genus by the presence of the former, as well as by the presence of subumbral muscle bands along the canalar radii; *borchgrevinki* by the gonads. The presence of a well-marked apical exumbral depression, coupled with an evident tendency for the centripetal canals to continue blind, even at maturity, is a good mark of identification for *typa,* for while the depression might seem a trivial feature, its presence, not only in Fewkes' (1882) original specimen, but also in others collected many years later by the *Grampus,* and in five more in the

Arcturus collection (all from the same general region off the northeast coast of the United States) seems to establish its constancy.

Geometrica is equally marked off by one outstanding character, i.e., by the union (in the adult) of all the centripetal canals with the radials. The only other *Calycopsis* that at all approaches it in this respect (*papillata*) has well marked exumbral sculpture which *geometrica* lacks.

Simulans and *typa* form a natural group so far as general appearance is concerned—so closely, in fact, do they resemble each other that Vanhöffen (1911) classed the former as a synonym of the latter. However, all the specimens referable to *simulans* that have so far been seen (including the *Zaca* specimen described below) have differed from typical *typa* not only in lacking any trace of apical depression, or of the egg-shaped swellings on the gonads that appear characteristic of the latter, but also in the fact that for them the number of canals appears to be determinate (12) instead of variable. Among the examples of "*simulans*" so far recorded, one from the Philippines (Bigelow, 1919) is set apart by the facts that most of the centripetal canals are fused with the manubrium instead of ending blindly, and that there are eight small tentacles in addition to the twelve that correspond to the canals. Whether this represents a geographic variation—i.e., that development progresses further in this respect in one race of *simulans* than in another—or whether the Philippine example actually belongs to some form as yet unnamed, is a question for the future.

Chuni, to judge from Vanhöffen's (1911, Pl. 22, Fig. 8) picture, must be grouped in its general organization with the *typa-simulans* group. However, its canals (27, 36) are somewhat more than twice as numerous as its tentacles (16, 17), whereas in *typa* and in *simulans,* the tentacles are at least as numerous as the canals. *Valdiviae* (to judge from the only adult yet seen) is set apart by the very large number (60) of canals, just commented upon, combined with absence of mesenteries. In *bigelowi* the numerical ratio of tentacles (48, large and small) to canals (8) is much larger than in any other member of the genus. And while the small size of the one specimen so far seen (only 12 mm. high) might suggest that it was a juvenile, the well-developed gonads argue against this view. Vanhöffen's (1911, p. 218, Fig. 12) illustration also suggests that part of the tentacles remain permanently small. *Simplex,* finally, while agreeing with *bigelowi* and *borchgrevinki* in the small number (8) of canals, is separated from the former by the fact that it has only about ⅙ as many tentacles (8), and from the latter by the structure of the gonads. It may be the juvenile of some other form.

It appears, in short, that while the various named members of the genus are closely allied, one to another, most, at least, of them differ sufficiently to be accepted as good species until intermediates be actually found. Their geographic distribution tends to strengthen this conclusion. Thus, specimens with apical depression (*typa*) have been taken only off the continental slope of North America; those agreeing with the original specimens of *simulans* only off the west coast of Central America; those with labial nematocyst knobs (*nematomorpha*) only in the Bering Sea region; those with the *borchgrevinki* type of gonads only in high southern latitudes; those with the *geometrica* type of canalization are known only in the Philippines and East Indies; the *simplex* type only from Norway; those of the *bigelowi* and *chuni* types from the Gulf of Aden.

Specimens with warty marginal lobes have, it is true, been recorded widespread, i.e., from the Florida-Bahamas region (*papillata,* Bigelow, 1918), from the vicinity of the Cape Verde Islands (Vanhöffen, 1912), and from the Alguhlas current by Vanhöffen (1911) as "*typa,*" this last being the specimen on which Hartlaub (1914) subsequently founded the species *valdiviae.* But *papillata* and *valdiviae* differ so widely in other respects (as

emphasized above) that there can be no question of their identity. And the description of the other warty specimens recorded by Vanhöffen (1912, as "*typa*"[3]), classed tentatively by Hartlaub (1914) as juveniles of *valdiviae,* are not detailed enough for positive identification.

The following artificial key to the species of *Calycopsis* may be helpful for purposes of identification:

1. With labial nettle knobs and subumbral muscle bands.... ..... *nematophora* Bigelow
   Without labial nettle knobs or subumbral muscle bands.....2
2. All centripetal canals join the radial canals at various levels..... *geometrica* Maas
   Most of the centripetal canals either end blindly, or join the cruciform base of the manubrium.....3
3. With about 60 canals at maturity.....*valdiviae* Hartlaub
   With 40 canals, or fewer.....4
4. Gonads in pockets.....*borchgrevinki* Browne
   Gonads in exterior folds.....5
5. Exumbrella with well-marked apical depression.....*typa* Fewkes
   Without apical depression 6
6. Many more canals than tentacles.....*chuni* Vanhöffen
   Tentacles at least as numerous as canals.....7
7. Marginal lobes with well-marked exumbral papillae.....*papillata* Bigelow
   Marginal lobes smooth or nearly so.....8
8. Many more tentacles than canals.....*bigelowi* Vanhöffen
   Number of tentacles and canals about equal.....9
9. Centripetal canals all adradial.....*simulans* Bigelow
   Centripetal canals interradial.....*simplex* Kramp & Damas

Calycopsis simulans Bigelow.

Sibogita simulans, Bigelow, 1909, p. 213, Pl. 5, Figs. 4, 5; Pl. 41, Figs. 8, 9; Pl. 43, Figs. 1, 2; 1913, p. 21; Mayer, 1910, p. 187.

Calycopsis simulans, Hartlaub, 1913, p. 360; Bigelow, 1918, p. 377.

Calycopsis typa (Partim), Vanhöffen, 1911, p. 214.

? *Calycopsis typa* var. *simulans,* Bigelow, 1919, p. 292, Pl. 40. Fig. 8; Pl. 41, Fig. 1.

Material: Sta. 233, 910-0 meters, one specimen, in good condition, about 26 mm. high by 25 mm. broad.

The *Zaca* capture corroborates the evidence afforded by the two specimens from between Panama and the Galápagos, for which the species was originally established, that the final number of canals in *simulans* is 12, i.e., 2 centripetals in each quadrant. In the original specimens these all ended blindly, though in their growth they had reached nearly to the cruciform base of the manubrium[4]. And this is true also of the *Zaca* specimen, though in this case the canalar terminations come so close to the manubrium that careful examination was required to demonstrate the discontinuity. It also agrees with the type specimen in the presence of as many large tentacles (12) as canals, one of the former opposite each of the latter. The fact that specimens apparently adult (to judge from the gonads) from

[3] Among three juveniles recorded as *typa,* two from the tropical Atlantic and one from the Indian Ocean, Vanhöffen (1911, p. 364) states that the wartiness was especially prominent after alcoholic preservation, which identifies the specimens as above.

[4] As pointed out elsewhere (Bigelow, 1913, p. 23), it is probable that a specimen from Bering Sea originally referred by me to *simulans,* in which the canals all join the manubrium (Bigelow, 1909, p. 214, Fig. 2), actually belonged to *C. nematomorpha.*

the same general region, but taken 32 years apart, agree so closely in these respects makes it likely that this is the final state. And for this reason it may finally prove necessary to find a new name for the Philippine specimen, originally described by me (1919) as var. *simulans* of *typa*, but in which all but one of the centripetals had already fused with the manubrium though the medusa was only 16 mm. in diameter, and in which there were eight small tentacles, besides the twelve larger ones connected with the canals (p. 292).

I need only note further that the tentacles, like those of the original specimens—of most other members of the genus, in fact—are tipped with prominent nematocyst knobs; that the sexual folds correspond closely to those of the type in regularity and general arrangement, and that there is no trace either of an apical depression or of exumbral papillae on the marginal lobes.

In the preserved condition the manubrium is pale ochre, the tentacles colorless.

The fact that the *Albatross* specimens were taken at the surface makes it likely that the present example was picked up by the net at a small depth, either on its way down, or its way up.

Bougainvilliidae.

Chiarella.

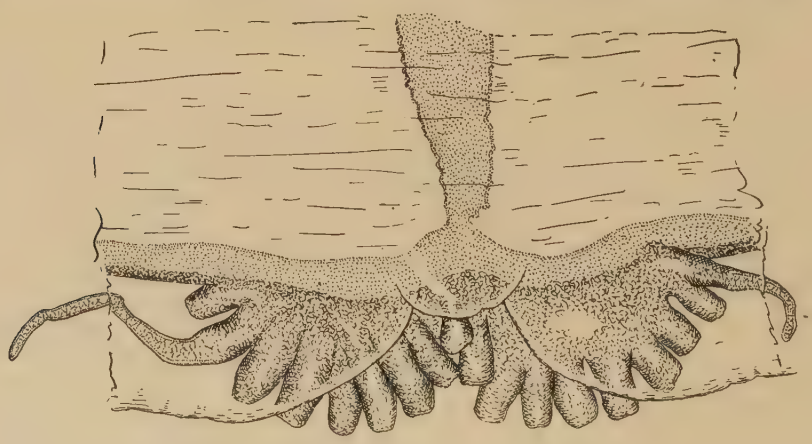
Chiarella centripetalis Maas.

(Text-figs. 11, 12).

Chiarella centripetalis, Maas, 1897, p. 15, Pl. 2, Figs. 1-4; 1905, p. 13; Mayer, 1910, p. 182; Foerster, 1923, p. 29.

Material: Stas. 139, 148, 159, in hauls respectively from 549-0, 549-0, 910-0 meters, 5 specimens, about 20-25 mm. high.

This large and easily recognized species had not been reported since originally described by Maas (1897) from specimens taken in the Gulf of California in 1891 by the U. S. Fish Commission Steamer *Albatross*. The



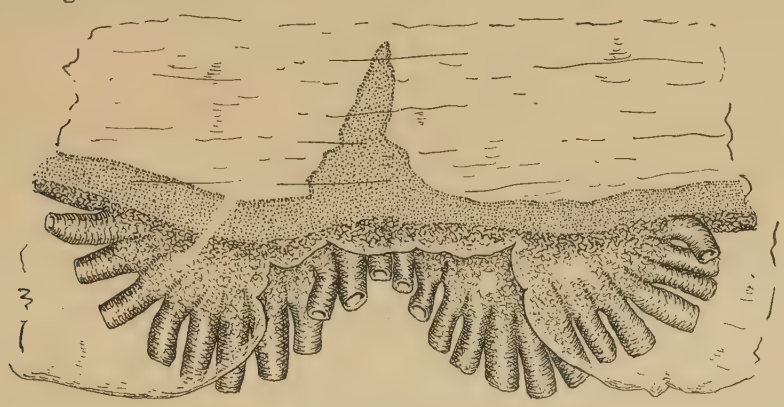
Text-fig. 11.
Chiarella centripetalis Maas, from Sta. 159, radial group of tentacles, camera drawing, about × 13.

Zaca captures in the same general region are, therefore, of considerable geographic interest.

The specimens, though all more or less damaged, are in good enough condition to show that in most respects they agree with Maas' account so closely that there is no doubt of their specific identity. This applies, in particular, to the general form of the bell; to the outlines and lengths of the spur-like interradial centripetal canals (Text-fig. 12), to the conformation of the gonads and to the basic arrangement of the eight groups of tentacles, by which the genus is characterized. Conspicuous, in particular, is the epaulette-shape of the basal folds from which the tentacular filaments arise (Text-figs. 11, 12), and the adradial series of transverse sex folds in the manubrial wall, which, in two of the *Zaca* specimens, are packed with large eggs.

The peduncle is considerably longer in four of the five *Zaca* specimens (the condition of the fifth is not good enough to show this) than in Maas' (1897) illustration based on a sketch from life, occupying in the extreme case, about ⅓ of the length of the bell cavity. But as there is a considerable variation in this respect within the series, and as all of them are in a flaccid condition in weak formalin, it is probable that this apparent difference between the collections of 1891 and of 1936 is the result either of different states of contraction or of preservation.

It is also worth mention that the margins of the radial canals (at least in the better-preserved examples) are slightly irregular or wavy though never definitely lobed—a feature not mentioned by Maas. The ring canal is smooth-edged.



Text-fig. 12.

Chiarella centripetalis Maas from Sta. 139, interradial group of tentacles, camera drawing, about × 16.

According to Maas (1897, p. 16) there are about as many tentacles in the interradial groups as in the radials (more than 40 in each, a total of more than 320). However, he does not state whether an individual count was made of any group other than the one pictured. And the *Zaca* series proves not only to be more variable in this respect, but with the number averaging only about half as great in specimens of the same size, the numbers being as follows for the groups for which counts are possible:

Approximate bell height	Radial groups	Interradial groups
24 mm.	19, 19, 20, 18	16, 16, 17, 19
23 mm.	18, 19	16, 25
21 mm.	22, 22±, 25±, 33±	24, 23, 31, 38±
20 mm.	23±, 24±, 24±	28±, 27±, 24, 24±
25 mm.	not more than 20 in any group	

The spacing around the bell margin is also variable, for while in the 24 mm. and 25 mm. specimens, all the epaulettes are approximately equal in breadth and of approximately the same breadth as the interspaces, in the 21 mm. specimen the interradial group with 38 tentacles occupies practically the entire interspace between the two adjacent radial groups.

Maas remarked that "die einzelnen Fäden sind verhältnissmässig kurz, was nicht auf Rechnung ihrer Contraction zu setzen ist, wie Skizzen nach dem Leben zeigen" (Maas, 1897, p. 16). Similarly, in the *Zaca* series all the more central members of each group are not only mere stumps (Text-figs. 11, 12) but such of them as are in good condition are rounded at the ends. But in several of the better-preserved groups the one or two tentacles near the outer margin extend as well developed though short filaments (Text-fig. 11), suggesting that all the tentacles may have been extensible to at least this extent in life.

According to Maas there is an ocellus at the base of each tentacle, as also appears in his color sketch from fresh material (Maas, 1897, Pl. 2, Fig. 1). These are not visible on the *Zaca* specimens, but they may have faded in the preservative.

In the preserved state the manubrium varies between dull salmon-pink and ochre yellow; the tentacular pads are of various shades of reddish-yellow.

The original account includes no information as to the depth of capture. But the fact that all of the *Zaca* specimens were taken in hauls from considerable depths suggests that the normal habitat lies considerably below the surface.

LEPTOMEDUSAE.

Thaumantadidae.

Polyorchis.

Polyorchis penicillata Eschscholtz.

Melicertum penicillatum, Eschscholtz, 1829, p. 106, Pl. 8, Fig. 4.

Polyorchis penicillata, A. Agassiz, 1862, p. 349.

To the synonymy given by Mayer, 1910, p. 218, add

P. penicillata, Foerster, 1923, p. 32; and

P. minuta, Murbach & Shearer, 1902, p. 72; 1903; p. 174, Pl. 19, Fig. 3, Pl. 22, Fig. 1.

Material: Inez Bay, 1 specimen about 10-12 mm. in diameter.

In this specimen, less than half grown to judge from the size to which the species attains in Californian waters (Mayer, 1910, p. 218; Foerster, 1923, Table, p. 34) there are 31 well developed tentacles, as well as three (or perhaps four) rudimentary tentacular knobs; or a number nearly as great as given by Mayer for the adult. However, Foerster (1923, p. 32) records an average of 64 tentacles (or 16 per quadrant) for large specimens, suggesting that the *Zaca* example was about half grown as regards number of tentacles as well as in size.

According to Fewkes (1889) and to Foerster (1923) the edges of the radial canals already bear small projections even as early as the 16-tentacle stage, foreshadowing the lateral diverticula characteristic of the adult *Polyorchis.* And the latter author (1923, p. 34) records their number as "fairly constant, i.e., 30-40, for small as well as for large specimens." In the *Zaca* example the edges of the canals are at most slightly wavy, at a stage in growth at which Californian specimens show well developed diverticula. Since, however, this is the only feature differentiating this specimen

from its confreres in more northern waters, it does not seem sufficient to warrant even a distinct racial name.

Previous records for *Polyorchis penicillata* were wide-spread between northern Vancouver Island and Santa Barbara, California. The *Zaca* capture is interesting chiefly for extending the known range of the species southward to the Gulf of California.

LAODICEIDÆ.

Chromatonema.

I have recently (1938, p. 109) given reasons for retaining this genus among the Leptomedusae as a member of the Laodiceidae, rather than classing it among the Anthomedusae as Ranson (1936) has done. The reader is also referred to Kramp (1919, p. 14) for discussion of the differences in gonad structure between *Chromatonema,* in which the gonads are broken up into a series of discontinuous masses, and in *Ptychogena,* where the gonad developed along either side of the pinnate radial canal is continuous. Named forms referable to *Chromatonema* as defined by Kramp (1919) are *rubrum* Fewkes, from the north Atlantic, *erythrogonon* Bigelow from the eastern tropical Pacific, and *hertwigi* Vanhöffen from the Indian Ocean. These are so closely allied that they may finally prove to be races or local varieties of one wide ranging species, but the recorded differences seem sufficient for the retention of all three names, at least for the time being.

Chromatonema erythrogonon Bigelow.

Text-fig. 13.

Ptychogena erythrogonon, Bigelow, 1909, p. 150, Pl. 5, Fig. 1; Pl. 38, Figs. 8, 9; Pl. 39, Figs. 1-7; Vanhöffen, 1911, p. 220.

Chromatonema erythrogonon, Kramp, 1919, p. 11; 1933, p. 553.

Chromatonema rubrum (Partim), Ranson, 1936, p. 102.

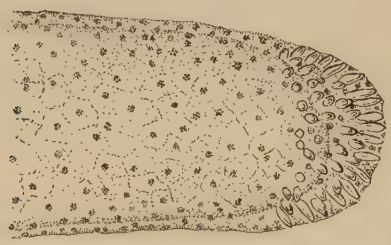
Chromatonema rubrum var. *erythrogonon,* Ranson, 1936, p. 105.

Material: Stas. 139, 148, 219, 228, 244, in hauls from 910 and 914-0 meters, a total of 14 specimens ranging in diameter from about 15-16 to about 44 mm., all of them in more or less fragmentary condition.

The *Zaca* series corroborates Kramp's (1919, 1920) conclusion, based on the original account of *erythrogonon* (Bigelow, 1909), that the latter agrees in all important anatomical features (as it does in general appearance, including color) with the Atlantic *C. rubrum.* Microscopic examination of the marginal organs in the *Zaca* specimens, and reexamination of the original material of *erythrogonon,* also shows that absence of nematocysts in the cordyli of *erythrogonon*—mentioned by Kramp (1919, 1920) as a possible distinction—is only apparent, i.e., that my earlier illustration (1909, Pl. 38, Fig. 8) was faulty in this respect. Actually (Text-fig. 13), the tips of the cordyli are crowded with minute, fusiform nematocysts in the Pacific form, just as in the Atlantic. And Kramp was no doubt correct in considering what I named "cirri" (1909, Pl. 38, Fig. 9) for *erythrogonon* as identical with the cylindrical cordyli in *rubrum;* especially since one *Zaca* specimen bears two cordyli intermediate between the two extremes; whereas in none of them have I been able to detect anything that could be described as a "cirrus."

It appears, however, that on the average the Pacific form develops a somewhat larger number of tentacles than does the Atlantic. True, the discontinuity—if such exists—is not wide, for the largest (44 mm.) of the *Zaca* specimens and two others of 35-40 mm. have each 38-39 tentacles,

contrasting with a maximum of 20-24 in *C. rubrum* (maximum 7-8 per quadrant, Kramp, 1933, p. 552). But occasional specimens from the Pacific have considerably larger numbers, witness one *Zaca* specimen in which 57 can still be counted, also the presence of as many as 16 in a single quadrant of one of the original *Albatross* specimens, suggesting a maximum of perhaps 60-64, or a number 2-3 times as large as has yet been recorded for any specimen from the Atlantic. The variability in different sectors of the margin is further illustrated by one of the *Zaca* series (40 mm., Sta. 239) in which there are 6, 8, 13, and 11 or 12 in successive quadrants. The number of cordyli is also greater in *erythrogonon* than in *rubrum,* i.e., not far from 60 in specimens so far studied. However, there is no discontinuity in this respect between the two forms, the recorded maximum being up to 40-45 in *rubrum,* in which there are more often 2 than 1 between every tentacle, and sometimes no greater than this in *erythrogonon* in which there is more often 1 than 2 in each intertentacular gap. In the largest of the *Zaca* specimens, for example, with 38 or 39 tentacles, there is one cordylus, each, in 19 of the gaps, and 2 each in 14 of the gaps, i.e., a total of approximately 40. In another specimen the numbers in successive gaps were 1, 1, 1, 1, 2. However, three were observed in one gap.



Text-fig. 13.

Chromatonema erythrogonon Bigelow, surface view of tip of cordylus to show nematocysts, from a preparation stained in Delafield's haematoxylin, camera drawing, about × 350.

On the other hand, it appears that the number of sexual masses may average slightly smaller in *erythrogonon* than in *rubrum* (again, however, there is no discontinuity!), for in the latter this varies from 10-16 on either side of each radial canal (Kramp, 1933, p. 552), whereas among the *erythrogonon* so far seen, that were in good enough condition for the number to be determined, the maximum was 11, and most frequently 9 or 10. A minor difference that the future may or may not prove characteristic is that in *rubrum,* so far as known, the free-hanging portion of the manubrium is quadrate, but barrel-shaped in *erythrogonon.* It also appears that at maturity, *erythrogonon* tends to attain a larger size (up to 44 mm.) than does its Atlantic relative (recorded maximum, 27 mm.).

Vanhöffen's (1911) *hertwigi* from the Indian Ocean—if the single specimen was representative—appears to be characterized by a much larger number of cordyli[5] (5) between every two tentacles than has ever been recorded, either for *rubrum* or *erythrogonon.* It agrees with the former, however, in the fact that the mouth was distinctly quadrate, and also in the number (20) of tentacles although it was much larger in size, i.e., 50 mm. in diameter.

The *Zaca* specimens are not in good enough condition to add anything important (other than as above) to the earlier account of *erythrogonon.* They do, however, provide interesting evidence of the constancy of coloration in this species, the tentacular bulbs, manubrium, and distal parts of the radial canals of the one specimen that is in good enough condition to show these being of the same brick-red (pale along the lines of attachment to the subumbrella and with pale cross at the base of the manubrium) and

[5]Vanhöffen names them "cirri," but his illustration (1911, p. 220, Fig. 13b) shows that actually they correspond to the cordyli of other members of *Chromatonema.*

the sexual blocks of the same salmon-pink as in the original series. In fact, all known representatives of *Chromatonema* agree in this respect.

The geographic range of *C. erythrogonon* appears to be decidedly circumscribed, for it has so far been taken only off the coasts of South and Central America between Latitude about 13° South (*Albatross* Sta. 4675) and the Gulf of California (*Zaca* Stas. 139, 148). And being so large, and so conspicuous in color, it is not likely that it would have been overlooked in the collections that have been made around Japan, around the Hawaiian Islands, and in Philippine waters, did it occur there as frequently as it evidently does in the eastern side of the Pacific at comparable latitudes. In this respect it appears to differ from its Atlantic confrere, the distribution of which is general from the continental slope of America to northern Europe as well as seemingly more northerly, for its known range extends up to Davis Strait and the vicinity of Iceland (Kramp, 1919, Chart I, p. 13; 1920, p. 8), whereas it is not known farther south than the vicinity of Bermuda (Bigelow, 1938).

Aequoridae.

Zygocanna.

Zygocanna vagans Bigelow.

Text-fig. 14.

Zygocanna vagans, Bigelow, 1912, p. 255; 1919, p. 315, Pl. 42, Figs. 5-7; Pl. 43, Fig. 6.

Material: Sta. 225, 910-0 meters, 2 specimens, 40 and 33 mm. in diameter. Sta. 233, 910-0 meters, 2 specimens, 33 and 34 mm. in diameter.

These specimens all agree so closely with the type series of *Z. vagans* (Bigelow, 1912; 1919) that there is no doubt of their identity though the locality of capture is in the opposite side of the Pacific. They add, however, to our knowledge of the species by showing that the early branchings of the canals as indicated by the figures formed by the courses of the canal stripes on the aboral wall of the manubrium, not only are decidedly irregular (Text-fig. 14), but that the outermost branching of the canals is not as closely associated with the margin of the manubrium as it was in the original series, but may occasionally take place considerably centrifugal to the latter. Such for example is the case in one of the specimens from Sta. 233 (Text-fig. 14A). Furthermore, the sinus-like expansions of the gastric cavity along the lines of the groups of successively formed canals (Bigelow, 1919, p. 316), especially well developed in this specimen, show that no sharp line of demarcation can be drawn between manubrium and canal, in this highly variable species.

Associated, as I have pointed out, with this type of branching, the canals are in groups; the number of groups "varies according to the number of branchings which each main stem has undergone, and the number of canals varies from group to group" (Bigelow, 1919, p. 316). In the two members of the original series in which the four primary trunks could be identified, the number of canals from each that reached the ring canal varied between 5 and 12. In the present series again, in two specimens in which these primary trunks are identifiable, the number of canals to which each of the latter gives rise ranges between 4 and 7.

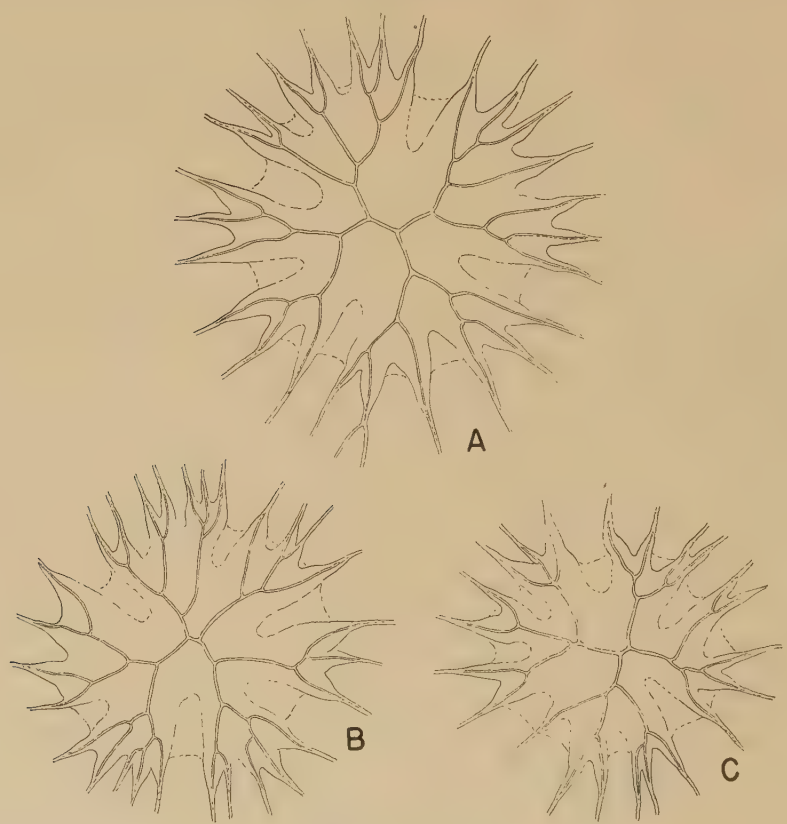
The smallest number of groups in which the canals are associated at the zone where they depart from the manubrium is 7 in the present series; the largest number is 10. The number of canals in a given group may be as small as 1 or as great as 8 even in different sectors of a given individual, the latter being the largest number yet observed.

The Philippine and *Zaca* series combined show that the numbers of canals and of tentacles tend to increase (though irregularly) with the growth of the medusa, as follows:

Diameter	Canals	Tentacles	Ratio tentacles to canals
*29 mm.	33	42	1.3
31 mm.	27	32	1.2
32 mm.	22	33	1.5
34 mm.	26	30	1.2
*36 mm.	29	28	1.0
38 mm.	30	30	1.0
*39 mm.	38	54	1.4
*40 mm.	35	42	1.2
*43 mm.	46	46	1.0
*50 mm.	31	45	1.5
*68 mm.	45	50	1.1
*76 mm.	38	70	1.8

* Philippine specimens.

As the larger of the Philippine specimens had well-developed gonads, it is probable that the final number of canals is not likely to be much more than 45 in any specimen—perhaps not less than 35.



Text-fig. 14.

Zygocanna vagans Bigelow, central portions of discs of specimens from Stas. 225 (A) and 233 (B, C) to show canal stripes, camera drawings, about × 3.

In two, only, of the specimens so far examined, was the number of tentacles less than that of the canals; greater by at least 1 in all others. But comparison between size, number of canals and number of tentacles (ratios —, Table, p. 300) fails to suggest any general tendency for the disparity in number between the two classes of organs either to increase or to decrease with the growth of the medusa.

In the one member of the original (Philippine) series, on which a complete count of the marginal organs was made, there were from 4 to 11 rudimentary tentacular knobs between every two large tentacles. The fact that among the *Zaca* specimens the number was in one instance as small as 1 but frequently as large as 7, further emphasizes the wide variations in this respect that are to be expected in different sectors of the margin, in individual specimens.

The large size of the excretory papillae has already been commented upon in the original accounts of the species (Bigelow, 1912; 1919, Pl. 42, Fig. 6), which the *Zaca* series confirms.

In all of the present series, the gonads (immature) are confined to the outer ¼ or so of the radial canals. The condition, however, of the type specimen of 39 mm. (Bigelow, 1919, Pl. 43, Fig. 61) shows that they may already occupy more than ½ the lengths of the canals in medusae no larger—another evidence of variability of the species.

The subumbral gelatinous papillae, characteristic of the species, occupy the same locations in the *Zaca* series as in the original specimens, being confined to a row between every two adjacent canals and to the roof of the manubrium. The intercanalar rows consist in some cases of entirely separate conical prominences, in others of a sharp crest bearing such; the number along each series varies from 1-9, as against 5-10, with a maximum of 15 in the Philippine series. As in the latter the papillae are confined to the inner ⅔ or ¾ of the bell diameter. The chief difference in sculpture between the *Zaca* and Philippine specimens is that the latter had up to 16 rounded knobs within the limits of the manubrium, whereas the largest number of such knobs among the *Zaca* series was only three. But in view of variability in other characters this difference does not seem specifically significant.

The most interesting aspect of the present captures is evidence of the wide-ranging nature of *Z. vagans.* The facts not only that *vagans* has now been found in both sides of the Pacific, but that all representatives of *Zygocanna* recently taken are referable to it, raises the question whether the regular bifurcation of canals well distal to the margin of the manubrium described and figured by Haeckel (1879) for his *Zygocanna costata* from New Guinea correctly represented the normal state, or whether it actually represents Haeckel's idealization of the alcoholic specimen on which he based the species (and genus). Even in the latter case, however, there remains to separate *vagans* from *costata* the presence of the subumbral papillae in the former, contrasted with their absence (or at least with Haeckel's failure to mention them) in the latter; and of radial exumbral ridges in *costata* of which there is no trace in *vagans.* The *Zaca* series does not help toward a final decision as to whether Mayer (1910) was correct in uniting *costata* with Péron & Lesueur's (1809) old species *pleuronota.* However, the fact that the members of two successive series of *vagans* (taken so far apart in time and in space) lack any trace of peduncle, argues against Mayer's (1910, p. 339) suggestion that Haeckel's *Zygocannula* (with well-developed peduncle) is an advanced stage of *Zygocanna.*

TRACHOMEDUSAE.

Geryonidae.

Liriope.

Liriope tetraphylla Chamisso & Eysenhardt.

Geryonia tetraphylla, Chamisso & Eysenhardt, 1821, p. 357, Pl. 27, Fig. 2.

For recent discussions of this (apparently) monotypic genus, see Browne (1924); Thiel (1936); and Bigelow (1938).

Material: Sta. 227, 210-0 meters, one specimen about 12 mm. in diameter.

In this specimen the gonads are triangular, with their bases occupying most of the periphery of the bell, but not yet actually in contact, i.e., it is intermediate between the so-called *"rosacea"* and *"compacta"* stages already pictured from the Eastern Tropical Pacific (Bigelow, 1909, Pl. 3, Figs. 7, 8). *Liriope* with gonads of this type has so frequently been reported—especially from the high seas—that the present example adds nothing significant to our previous knowledge of this much-vexed genus.

Trachynemidae.

Colobonema.

Colobonema typicum Maas.

Homoeonema typicum, Maas, 1897, p. 22, Pl. 3, Figs. 1-3.

For recent discussion of the synonymy of this species, see Bigelow, 1938, p. 116.

Material: Sta. 219, 540-0 meters, 1 specimen, about 25 mm. high.

This specimen—in good enough condition for positive identification—adds nothing to previous knowledge of the morphology of this well-known bathypelagic medusa. Having been taken widespread in the Eastern Tropical Pacific, including the offing of Costa Rica and Gulf of California (Maas, 1907; Bigelow, 1909), it is somewhat astonishing that the *Zaca* collection yielded only a single example of it.

Halicreidae.

Halicreas.

Halicreas minimum Fewkes.

Halicreas minimum, Fewkes, 1882, p. 306.

Halicreas papillosum, Vanhöffen, 1902a, p. 68, Pl. 9, Figs. 7-8; Pl. 11, Fig. 30.

For reasons for the final relegation of *papillosum* to the synonymy of *minimum,* and for lists of the more important references, see Bigelow, 1938, pp. 121, 122.

Material: Stas. 165, 210, 225, 227, 228, 230, 234, 15 specimens, all in hauls from 910-0 meters.

The condition of the specimens is so poor that they add nothing to previous accounts of this well-known species. All, however, show the characteristic exumbral papillae, and it is chiefly on these that their identification rests.

Having already been recorded at many stations in the eastern side of

the Tropical Pacific (Bigelow, 1909), *H. minimum* was to be expected in the region explored by the *Zaca.* It is, in fact, now known to be one of the most generally distributed and frequently occurring of bathypelagic medusae in the open oceans, in low and mid-latitudes, as discussed elsewhere (Thiel, 1936, p. 72; Bigelow, 1938, p. 122).

NARCOMEDUSAE.

Solmaridae.

The majority of recent authors have concurred in uniting in this one family all Narcomedusae that lack gastric pockets. Ranson (1936), on the other hand, has revived the old family designation Peganthidae, for such of them as have the gonads localized in interradial diverticulae of the gastric wall, as opposed to those in which they extend, ring-like, right around the margin of the stomach. To use the conformation of the gonads as a basis for family separation among the Narcomedusae that lack gastric pockets would, however, run counter to another set of alternative characters, namely, the presence or absence (at least in one generation) of a canal system and of otoporpae. Our knowledge of the existence of solmarids with canals and otoporpae, but with a simple annular gonad, rests not only on Haeckel's (1879; 1881) account and figures (from life) of his *Polycolpa forskalii* from the Red Sea, but equally on Browne's (1916) discovery of a second unnamed Narcomedusa of this type from the Indian Ocean. In fact, the *Cunina prolifera* of Gegenbaur (for synonymy, see Mayer, 1910, p. 480), which also has an annular gonad and otoporpae, appears also to belong to this group, for none of the published illustrations of this species show any gastric pockets. Stschelkanowzew (1906, p. 483) indeed states definitely that it has none, but that its stomach, is perfectly round in life, though taking an angular outline when preserved as is shown by Mayer (1910, p. 471, Fig. 319A). *C. prolifera* should then be removed from the Aeginidae to the Solmaridae (and referred to *Polycolpa* if that genus be recognized, see below) as Stschelkanowzew suggested, though he did not actually go so far as to make this alteration.

The question is further complicated by the fact that the canals and otoporpae, so conspicuous in the primary generation of *Pegantha* are lacking in the second parasitic generation that develops within that genus, at least up to the most advanced stage to which development has been followed (Bigelow, 1909, p. 93), so that morphological diagnosis that applies to one generation would not to the other. It therefore seems wiser to maintain the family Solmaridae as widely inclusive for the time being; admitting, however, that this may be only a temporary stand, in the slow and spasmodic growth of our knowledge of the Narcomedusae.

Within the Solmaridae, as thus conceived, three groups of species appear to be rather definitely definable: A, with simple annular gonad, lacking canals and otoporpae; B, with simple annular gonad, with canals, and with otoporpae; and C, with interradial sexual sacs (whether or not combined with an annular gonad), with canals, and with otoporpae. The first of these groupings is now generally referred to *Solmaris;* the second is the genus *Polycolpa* of Haeckel (made by Mayer, 1910, a synonym of *Solmaris*); it is with the third that we are concerned here.

For the members of this last group, Haeckel (1879) revived the old genera *Pegasia* of Péron & Lesueur (1809) and *Polyxenia* of Eschscholtz (1829), as well as proposing his new genus *Pegantha.* And it is certain that in any final revision these two old generic names must be taken into account, for we have as good grounds for identifying them with the medusae in question, as in most of the cases in which final disposition of the early medusan names has been made.

Actually, it seems that the earliest description of a typical peganthid was neither of *Pegasia* nor of *Polyxenia,* but of the *Medusa mollicina* of Forskål (1775). This Péron & Lesueur (1809) later referred to their genus *Faveola,* but incorrectly since the first mentioned member (hence type species) of the latter—the *Medusa pilearis* of Linnaeus (1766)—was an Anthomedusa and probably what is now known as *Leuckartiara.* The next description of what was probably a peganthid (though no indication was given as to presence or absence of a canal system nor of otoporpae) was by Eschscholtz (1829) as *Polyxenia cyanostylis.* Meantime, however, Péron & Lesueur (1809) had published a brief notice of *Pegasia dodecagona.* And while their account and the subsequent illustration by Blainville (1834) are unrecognizable if taken *per se,* Haeckel (1879, p. 331) from personal examination of one of Péron & Lesueur's original specimens, placed it in his family Peganthidae—thereby at least implying a lack of gastric pockets, but presence of a peripheral canal system—described its gonads and even counted the otocysts. Our choice lies, then, between ignoring Haeckel's diagnosis as Vanhöffen (1908) has done (partly on the ground that it was not accompanied by an illustration) or accepting *Pegasia* as the oldest generic name applicable to the group in question. And the latter alternative appears much the more likely to conduce toward stability of nomenclature. In other words, we can credit Haeckel with doing for *Pegasia* what Chun (1897) did for *Abylopsis tetragona* Otto, among siphonophores, i.e., with establishing the status of an old species from reexamination of a type specimen, the original account of which had been wholly inadequate, or even erroneous.

Accepting the validity of the name *Pegasia,* we have still to decide whether all known members of the group to which it belongs (i.e., solmarids with otoporpae, with canals, and with genital diverticulae) should be referred to it, or whether they represent more than one genus. Generic grouping based on the number of tentacles, suggested by Vanhöffen (1908; 1911; 1912) having been proven untenable in this case, decision rests on what value in classification is to be assigned to the conformation of the gonads. And while Vanhöffen (1908), Mayer (1910), and subsequent authors generally have been of the opinion that this is not of more than specific import in the group in question, it seems wiser to reserve judgment, until the time (if ever), when some student has the opportunity to examine actual specimens in which an annular gonad is combined with interradial sexual sacs—i.e., referable either to *Polyxenia,* or to *Pegasia* as redefined by Haeckel.

Accordingly, the generic name *Pegantha* is retained here (as earlier by me) with the Haeckelian diagnosis, i.e., for Solmaridae in which the sexual products are confined to interradial outpocketings from the gastric margin, irrespective of the number of tentacles. Should it prove, in the future, that the gonads must be discarded here, as a generic character, the name *Pegasia* (or if not *Pegasia,* then *Polyxenia*) will have priority.

Pegantha.

Anatomically, *Pegantha* is one of the best known of narcomedusan genera. Our knowledge, however, of specific relationships within the genus has not significantly advanced since 1918, when I briefly outlined the existing status in this respect (Bigelow, 1918, p. 395). Nor does the present series contribute toward a final solution, for one of the two specimens of *Pegantha* that it contains, belongs to a species that has already been fully described, while the other is not in good enough condition for positive identification.

Pegantha clara R. P. Bigelow.

Text-figs. 15, 16.

Pegantha clara, R. P. Bigelow, 1909, p. 80.

Pegantha smaragdina, H. B. Bigelow, 1909, p. 90, Pl. 14, Figs. 1, 2; Pl. 19, Figs. 1-9, Pls. 22-26.

To the synonymy and list of references given earlier by me (Bigelow, 1938, p. 134), add *P. smaragdina*, Hanitzsch, 1911, p. 225.

Material: Sta. 230, 910-0 meters, 1 specimen about 55 mm. in diameter with 25 tentacles, in fair condition.

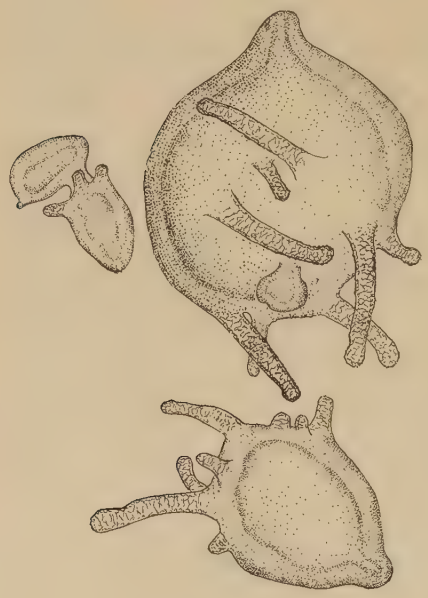
In its low disc without exumbral sculpture, and simple gonads (hemispherical when relaxed but more or less constricted when contracted), the *Zaca* specimen agrees very well with the earlier accounts by R. P. Bigelow of the Atlantic *P. clara* and by me almost simultaneously of *P. smaragdina* from the Eastern Tropical Pacific. The number of tentacles (25, 2 much smaller than the others) also falls well within the recorded limits (19-34). And this also applies to the number of otocysts, of which there are five (4 of them with well developed otoporpae, but 1 lacking such an organ) in the only sector in which they can be counted, and three, with otoporpae, close together in the next, so localized as to suggest a total of 6-8. In short, it corroborates the conclusion arrived at first by Vanhöffen (1912a) and subsequently by me (1938) that *smaragdina* cannot be distinguished specifically from *clara*. In my original (1909) discussion of the former it was suggested

Text-fig. 15.

Pegantha clara R. P. Bigelow, aboral view of gonads and canal system with polyp larvae, camera drawing, about × 7.

that the ova (difficult of detection because of their small size) may develop irregularly over the wall of the manubrium, as is the case according to Stschelkanowzew (1906) in *Cunina proboscidea,* i.e., that it may be the males alone that develop discrete gonads. In fact, ova have not been definitely identified as yet, in any *Pegantha,* so far as I am aware. And surface views of the sexual sacs of the *Zaca* specimen are at least compatible with this suggestion, no ova being visible, even after staining, but only very closely crowded masses of minute cells, suggesting stages in spermatogenesis.

Anatomically, the specimen is interesting as showing individual tendency toward abnormality, for the otoporpae vary greatly in length, while one of the peronii is abnormally broad distally, and bifid proximally, with a small tentacle associated with the one branch but none with the other, the two branches being separated by a canal, but one so much shorter than the others that it fails to reach the margin of the bell (Text-fig. 15).



Text-fig. 16.
Pegantha clara R. P. Bigelow, enlarged view of three of the larvae shown in Fig. 15, camera drawing, × 42.

The most interesting feature of the *Zaca* specimen is that its canal system contains several polyp-larvae (Text-fig. 16) with much younger (cleavage) stages in the mesoglea, agreeing very closely with those described by me (1909) for one of the two *Albatross* specimens from the Eastern Pacific. These have not been found in any Atlantic example of the species that has yet been examined. It is worth repeating, however, in this connection, that small medusae, resembling the 2nd generation of *P. clara,* have often been observed in the gastrovascular cavity of the Mediterranean Narcomedusa usually referred to in literature as *Cunina prolifera* Gegenbaur, but which is not a *Cunina* but a peganthid (p. 303). Unfortunately, the histological condition of the *Zaca* specimen was not good enough to add anything of moment to my earlier account of the developmental stages. Their presence, however, in this second example shows that it is characteristic of the earliest stages to be confined to the mesoglea of the exumbrella of the parent, overlying—in this case—the part of the vascular system that is

occupied by the older larvae. It is also interesting that the latter, like those earlier described, show stages in budding at the aboral side.

Were it alone in *P. clara* that this type of development had been observed, it might reasonably be questioned whether the resultant small medusae do indeed belong to the developmental cycle of the large medusae within which they occur, for we lack actual factual knowledge of the source of the infesting larvae. Since, however, Stschelkanowzew (1906) was able to show that similar larvae, found parasitic within *Cunina proboscidea,* develop from the fertilized ova of that same species, we may assume that the same is true of *Pegantha.*

In the case of *Cunina,* it appears, indeed, (from Stschelkanowzew's studies), that the larvae are the offspring of the same individuals within which they develop. Since, however, the larvae have now been found in a specimen of *P. clara* lacking any trace of gonads, and in a second in which the latter are well developed, it seems that in this species any large individual (whether or not mature) may become infested if in the vicinity of others that are actually setting free their eggs and sperm in the water. And this seems the more likely, from the fact that in this particular Narcomedusa (in contrast to *Cunina proboscidea*) the earliest developmental stages are to be found in the exumbral mesoglea. In other words, there is no necessity for assuming that the larvae found within a given individual are its own offspring. But this whole matter necessarily remains open, until the fertilization of the egg and its actual penetration have been traced.

According to Hanitzsch' (1911) interpretation, based on Stschelkanowzew's (1906) cytological studies of the oogenesis of *Cunina,* the mitotically dividing amoeboid cells of *P. clara* (Bigelow, 1909, Pl. 22, Figs. 8, 9) represent the product either of the last maturation or of the first cleavage division, and those amitotically dividing (which later act as the nurse cells for the embryo) are oocytes that have lost their character as sex cells.

A serious gap still remains in our knowledge of the developmental cycle of *P. clara,* between the medusae of generation II (i.e., the small parasitic) which are set free at what may be termed the "*Solmissus*" stage when some 3 mm. in diameter, and those of generation I, within which they have been found. In the case of *Cunina proboscidea* Stschelkanowzew (1906) concluded that an asexual polyp generation intervenes, both because the direct development of the medusae of generation II into those of generation I seems precluded by differences in structure, and because he believed he could identify as the young of *C. proboscidea* (by the shape of the otoporpae) the medusae set free from one of the two species of narcomedusan stolons that are often found parasitic within the gastric cavity of *Geryonia.*[6] Metschnikoff (1874, p. 34) had in fact made this same suggestion, long before. These stolons, as is well known, are the growth products of ciliated larvae, which Woltereck (1905, Figs. 12-14) traced back to early cleavage stages in the mesogloea of *Geryonia.* But the actual process by which the latter is parasitized by them has not yet been observed; we have only Stschelkanowzew's suggestion, accepted by Hanitzsch (1921, p. 225), that the small medusae of *C. proboscidea* of generation II are eaten by the *Geryonia* and that their eggs and sperm come together within the cavities of the latter.[7]

Perhaps a stolon-generation intervenes, in *Pegantha clara* also, between the medusae of generations I and II. But it is equally possible that in this species the large medusae of generation I develop directly from the fertilized eggs of the small "solmarid" medusae of generation II.

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[6] These are the stolons usually referred to as "*Cunina parasitica* Metschnikoff."

[7] The development of *Cunina proboscidea* has been discussed not only by Metschnikoff (1886) and Stschelkanowzew (1906), but subsequently in great detail by Hanitzsch (1911-1921).

? **Pegantha martagon** Haeckel.

Pegantha martagon, Haeckel, 1879, p. 332; Bigelow, 1909, p. 83, Pl. 18, Figs. 1-8; Mayer, 1910, p. 443.

Pegantha simplex, Bigelow, 1904, p. 260, Pl. 5, Figs. 19, 20.

Material: Sta. 234, 1 fragmentary specimen, about 18 mm. in diameter, with 12 tentacles.

The condition of this specimen is not good enough for positive identification, further than that absence of gastric pouches and presence of a well-developed canal system prove it a *Pegantha.* It is tentatively referred to *P. martagon* for the following reasons: 1, the bell is high-rounded, but above the level of the tentacular insertions, shows no trace of the exumbral sculpture that is so prominent in *P. triloba;* 2, the gonads, while showing a certain amount of irregular wrinkling and lobing are not definitely subdivided. The margin is so much damaged as to prevent counting the otocysts; it is unfortunate, in particular that the otoporpae have been entirely destroyed, because the structure of these is one of the respects in which *P. martagon* differs the most sharply from *P. triloba* (Bigelow, 1909).

Solmissus.

Ranson (1936, p. 206) in his recent discussion of *Solmissus,* is of the opinion that *S. incisa* Fewkes is a "forme géante" of *S. albescens* Gegenbaur, but that the Indo-Pacific *S. marshalli* Agassiz & Mayer is a well defined species rather than a variety of *albescens* as I (1909; 1919) formerly suggested.

Solmissus marshalli Agassiz & Mayer.

Solmissus marshalli, Agassiz & Mayer, 1902, p. 151, Pl. 5, Figs. 23-25; Bigelow, 1909, p. 64, Pl. 16, Figs. 5-6, Pl. 21, Figs. 4, 6-8; 1919, p. 329; 1938, p. 129; Mayer, 1910, p. 484; Thiel, 1936, p. 68; Ranson, 1936, p. 208.

Solmissus punctatus, Mayer, 1906, p. 1133.

Solmissus flavescens, Vanhöffen, 1908, p. 56, Pl. 2, Figs. 9-10, Pl. 3, Figs. 20-22.

(*Non Solmissus flavescens* Kölliker).

Material: Sta. 233, 2 specimens respectively about 34 mm. and 52 mm. in diameter.

Tentative identification of these two specimens rests on the fact that, in each case, traces of the outlines of gastric pockets in the radii of the tentacular roots are still to be seen, combined with a flat-lenticular type of bell characteristic of *Solmissus* of the *albescens-marshalli* group. Failing any trace of the otocysts, and lacking knowledge of the precise contour of the gastric pockets, they are referred to *marshalli* on geographical grounds, because *albescens*—the common *Solmissus* of the Mediterranean—has not yet been taken in the Pacific.

Unfortunately, the condition of the specimens is so poor that the number of tentacles cannot be stated exactly, further than that in one case 8 large tentacular roots were detected and in the other nine. But these numbers are so much smaller than is usual in full-grown *marshalli* (usually 12-16) as to suggest that there had been more tentacles in life, but that some had been obliterated.

It has long been known that *marshalli* (or the *marshalli* variant of *albescens*) is widespread in the tropical and subtropical belts of the Pacific, Indian and Atlantic oceans, while Ranson (1936) has recently reported it from the Mediterranean.

Aeginidae.

Aeginura.

Recent authors agree that all representatives of *Aeginura* that have come to hand, subsequent to Haeckel's (1879) original account of the genus, are referable to the single species *grimaldii* Maas (1904)—of which *weberi* Maas (1905) and *grimaldii* var. *mundi, guinensis* and *obscura* of Vanhöffen (1908) are synonyms. The relationship, however, of *grimaldii* to the medusa (*myosura*) on which Haeckel founded the genus, and to Haeckel's *Cunoctona nausithoe* and *C. lanzerotae* (which are described as having otoporpae) is still in doubt; may, in fact, always remain so. Having recently (1938, p. 132) discussed this question, there is no need for me to revive it here.

Recent students of Narcomedusae have been unanimously of the opinion that the chief generic character of *Aeginura* is the constant presence of 8 tentacles and 16 gastric pockets; and it has seemed at least probable that the presence of small secondary tentacles on the margin is equally diagnostic, for while Haeckel (1879; 1881) neither mentioned nor pictured any such for *myosura,* their apparent absence in the latter may well have been due to the mutilated state of the unique (alcoholic) specimen. But it is now necessary to redefine the genus, or to institute a new one, for the *Zaca* collection contains a specimen that agrees with *Aeginura* in the arrangement of the gastric pockets in relation to the large primary tentacles, and in the presence of small secondary tentacles on the bell-margin between the peronii, but in which the number of tentacles, and of primary gastric pockets is eleven, instead of eight. Decision in this case obviously depends on the relative phylogenetic weight to be attached to metameral number, as compared with the presence of the secondary tentacles. About this opinions may differ. Since, however, the number of primary tentacles in the Narcomedusae may either be strictly determinate, as for instance in *Solmundella* and *Cunoctantha,* or highly variable as in some species of *Pegantha* and *Cunina,* whereas the presence of secondary tentacles is a feature peculiar (so far as yet known) to *Aeginura,* it seems to me wisest to use the latter as the primary generic character for that genus, expanding the latter to include species with more than 8 tentacles.

Aeginura beebei sp. nov.

(Text-figs. 17-20).

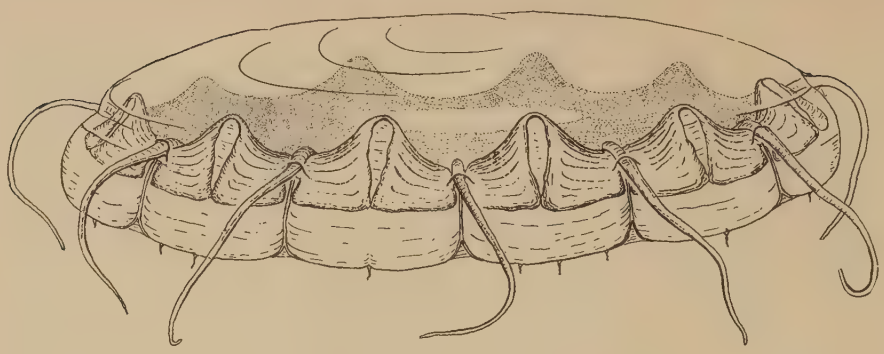
Material: Sta. 227, 910-0 meters, 1 specimen, about 100 mm. in diameter in fair condition.

This specimen (Text-figs. 17-20) is perhaps the most interesting find among the *Zaca* medusae, for while in general appearance it resembles *Solmissus,* critical examination shows that it actually agrees, in all significant anatomical characters, with the bathypelagic medusa *Aeginura grimaldii.* It differs, however, from the latter in the fact that it has (as just stated) a larger number of antimeres (11) than has ever been recorded for *Ae. grimaldii* in which the normal 8 has never been exceeded—though Ranson (1936, p. 210) records one specimen with as few as five.

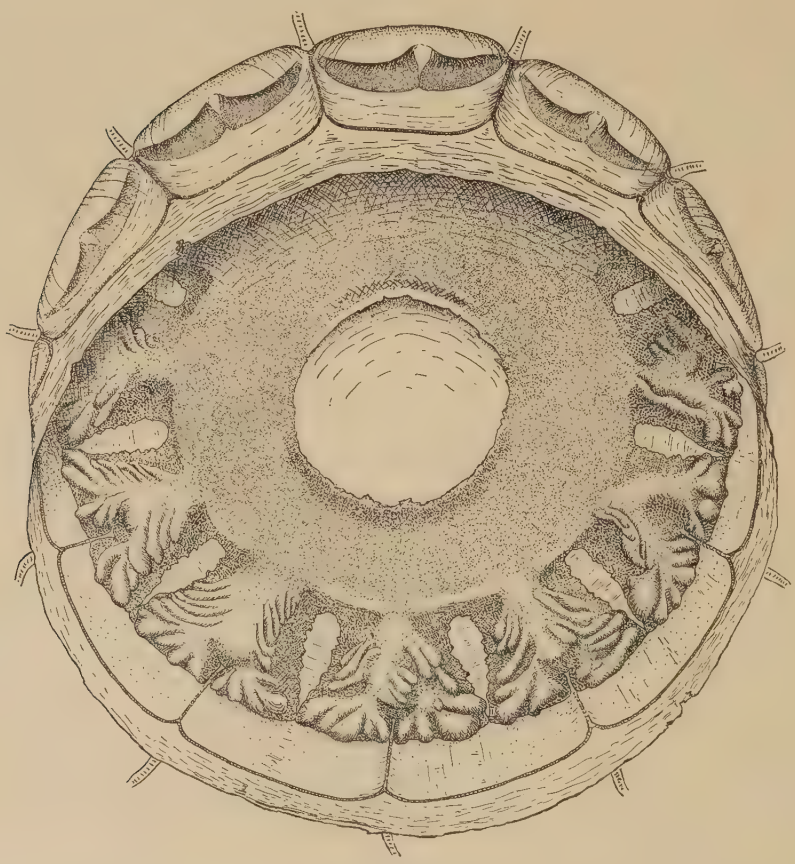
Most at least of the secondary tentacles are intact, and certainly a majority of the otocysts: the numbers of marginal organs counted per antimere, being as follows:—

Tentacles	3	1	2	2	1	1	3	1	2	1	2
Otocysts	5	2	4	1	2	3	6	3	3	2	2

Thus, there is no evidence that the number of secondary tentacles ever exceeds 3 per sector, while in at least 5 of the sectors, the condition of the



Text-fig. 17.
Aeginura beebei, sp. nov., lateral-oblique view of type specimen, slightly more than natural size.

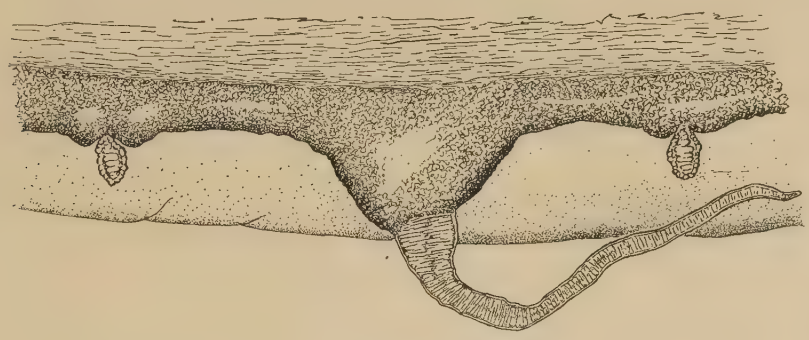


Text fig. 18.
Aeginura beebei, sp. nov., oral-oblique view of type specimen, slightly more than natural size.

margin was so good as to allow positive assertion that there was only one secondary tentacle. In *grimaldii* (or its synonyms), the recorded number per marginal sector ranges from 2 to 5, the total thus being about the same as in the new species.

Structurally, the secondary tentacles of *beebei* differ from the primary tentacles in the fact that they lack entodermal roots, while their bases are much swollen (Text-fig. 19), hence there is no reason to suppose that the former ever develop into the latter. In detail (i.e., in the core of chordate entodermal cells and in the slender filament) they agree very closely with Vanhöffen's (1908, Pl. 9, Fig. 28) illustration of the corresponding structures in his *"Cunoctana obscura,"* which was undoubtedly identical with *Ae. grimaldii.*

A secondary tentacle is flanked, in so many cases, by an otocyst on either hand (Text-fig. 19) that this appears to be the basic state. However, the presence of three otocysts each, in two of the marginal sectors but of only one secondary tentacle, proves that neither the numerical relationship between the two, nor their relative locations on the margin, are determinate. A similar variation in number and spacing of otocysts has already been recorded for *grimaldii* (Vanhöffen, 1908). On the average, the number of otocysts per sector (there being fewer secondary tentacles) is somewhat smaller in the new species than in *grimaldii,* but the difference may not be great enough to be of diagnostic significance. In their structure (Text-fig. 20) the otocysts are of the usual aeginid type.

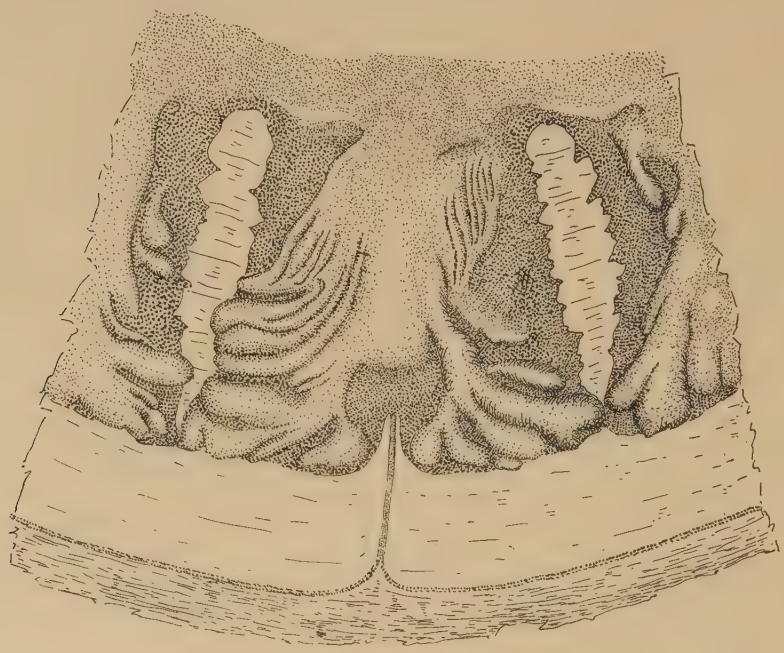


Text-fig. 19.

Aeginura beebei, **sp. nov., aboral view of portion of margin, with secondary tentacle and otocyst, camera drawing, × 66.**

The specimen corroborates previous observations to the effect that in *Aeginura* the interradial notches that indent the margin of the gastric cavity are much deeper than the perradial, such for example was the case in the specimen from the East Indies figured by Maas (1905) as *Ae. weberi;* in the *Albatross* specimens from the Eastern Tropical Pacific and Northwestern Pacific (Bigelow, 1909, p. 80; 1913, p. 62), and likewise in Maas' (1904, Pl. 3, Fig. 20) original figure of *Ae. grimaldii,* in which the interradial notches are pictured as about twice as deep as the perradial. Haeckel (1879; 1881), on the other hand, pictures the reverse for *Ae. myosura,* this being one of the reasons for doubting whether this species has been seen subsequently. In the *Zaca* specimen of *Ae. beebei,* the interradial notches are about 16-17 mm. deep, but the perradial only 4-5 mm. The gastric pockets themselves are rhomboid in outline (Text-figs. 18, 20), broader distally than proximally, with the outer angles of adjacent pockets very close together. Surface views, in fact, suggest that they may even be confluent, which would be unique among Narcomedusae. But the condition

of the specimen is not good enough for positive determination of this point, though it was easy to trace the general outlines of the pockets by surface examination, verified by the injection of air. A specific character, which, while minor in itself, is again unique, so far as known among aeginids, is that the interradial margins of the pockets are jagged or lobate (Text-fig. 20). Neither surface view nor injection yielded any evidence of the presence of a peripheral canal system, in which *beebei* agrees with *grimaldii.* The central part of the stomach has been largely torn away—the remnants, however, suggest a simple circular mouth (Text-fig. 18).



Text-fig. 20.
***Aeginura beebei*, sp. nov., oral view of gastric pockets, about × 3.**

The gastric wall, at the interradial sides of the pockets, is thrown into a series of folds directed obliquely distal (Text-figs. 18, 20), no doubt the sites of the sexual products. Surface views suggest that the specimen is a male—at least no individual eggs are to be seen. And to judge from analogy with *Ae. grimaldii,* the latter might be expected to be so large as to be conspicuous.

A striking feature of the specimen is that the subumbrella is deeply indented with triangular depressions along the lines of the interradial septa that separate the gastric pockets, and also with furrows along the perradial septa. Thus, were the gastric wall to be stripped off, the subumbral zone occupied by the pockets would appear as alternate triangular prominences and depressions, the former with their bases directed distally, and shallowly notched in the perradii, the latter with their bases directed toward the center of the bell. The bell is low discoid in form, about ⅙ as high (18 mm.) as broad, with very shallow bell cavity, i.e., hardly deeper than the breadth of the marginal groove. There is no exumbral sculpture, other than the shallow furrows along the lines of the peronii that are a common feature among Narcomedusae.

The gastric wall in the preserved state (formalin) is pale purplish. Otherwise the specimen is colorless.

The features in which *Ae. beebei* most sharply differ from *Ae. grimaldii* are 1, larger (and probably indeterminate) metameral number; 2, presence of prominent subumbral sculpture; 3, much larger size at maturity; 4, entire lack of the distinctive bathypelagic pigmentation.

Obviously, the one capture, having been made in an open net, yields no information as to the normal bathymetric occurrence of the species, but the fact that it is so faintly pigmented suggests that it is a creature of the upper waters.

Aeginura grimaldii Maas.

Aeginura grimaldii, Maas, 1904, p. 38, Pl. 3, Figs. 19-28.

See Bigelow, 1938, p. 132, for recent discussion of *Aeginura* with the reasons why it seems wiser to retain Maas' species *grimaldii* as distinct rather than to unite it with Haeckel's (1879) old species *myosura, nausithoe,* and *lanzerotae* as Thiel (1936) has done in his historical survey.

Material: Sta. 227, 910-0 meters, 1 fragmentary specimen about 23 mm. in diameter.

Sta. 228, 910-0 meters, fragments.

Aeginura grimaldii is represented so regularly in collections from deep water that it must be one of the most generally and frequently distributed of bathypelagic medusae. As a rule, however, the specimens taken have been badly damaged amid the mass of other plankton. And the present examples are no exception, for the one (Sta. 228) is made recognizable only by the pigmentation in combination with the fact that a few of the conspicuous white ova are still intact, while the other—in a somewhat better state—is so battered that only one of the secondary tentacles is still to be seen, and none of the otocysts. Hence they add nothing to previous accounts based on better material.

Aegina.

Aegina citrea Eschscholtz.

Aegina citrea, Eschscholtz, 1829, p. 113, Pl. 10, Fig. 3.

See Bigelow, 1938, p. 130, for the most recent discussion of this genus; Mayer, 1910, pp. 451-454, and Thiel, 1936, p. 73 (*"Ae. rosea"*), for lists of references to the various named representatives of *Aegina,* all of which probably refer to the one species, *citrea.*

Material: Sta. 210, 910-0 meters, 1 specimen about 17 mm. in diameter.

Sta. 230, 910-0 meters, 1 specimen about 22 mm. in diameter.

Both of these specimens are of the so-called *"rosea"* type, i.e., with the margins of the 8 adradial gastric pockets entire. A point still to be determined is the range of variation in number of otoliths that is normal for the species. In this connection it is interesting that in one quadrant of the specimen from Sta. 230 there are 14 of these organs—this probably being the complete number, since they are evenly spaced. This is somewhat fewer than recorded by Vanhöffen (1908a), namely, 16-20 per quadrant, but a larger number than reported by most other authors.

Beyond this, the present series calls for no special comment, for *Ae. citrea* has repeatedly been described and figured from specimens in better condition.

SCYPHOMEDUSAE.

CORONATA.

Periphyllidae.

Periphylla.

Periphylla hyacinthina Steenstrup.

Periphylla hyacinthina, Steenstrup, 1837.

For synonymy and recent discussion see especially Mayer (1910, p. 544, "*P. hyacinthina*"), p. 546 ("*P. hyacinthina* forma *regina*"); Broch, 1913, p. 4; Stiasny, 1934, p. 342; and Bigelow, 1938, p. 155.

Material: Stas. 148, 158, 210, 225, 227, 228, 230, 233, 234; a total of 22 specimens from about 15 to about 150 mm. in diameter at the level of the coronal furrow, all in hauls from 910-0 meters.

It now seems certain that all known representatives of the genus *Periphylla* actually belong to a single species. It also seems established that in general the "*dodecabostrycha*" form (small; low-rounded bell; transparent peripheral zone), the "*hyacinthina*" form (peripheral zone pigmented, bell usually high-arched, pointed), and the "*regina*" form (dense pigmentation, low-domed bell) represent successive stages in growth. But it is still an open question whether every *Periphylla* (if it survives) normally passes from the "*hyacinthina*" stage into the "*regina*" stage, or in what degree this basic succession may be confused by individual variation as to development of pigment, and as to bell-shape in relation to size. The fact that the largest specimens among the considerable series collected by Dr. Beebe near Bermuda during the years 1929 and 1930 (Bigelow, 1938, p. 156) were less than 60 mm. in diameter (at level of coronal furrow) but still referable to the "*hyacinthina*" stage also suggests that certain populations may fail to develop beyond this, before they die. It is in fact likely that this may apply to a considerable percentage of the individuals among other populations, some of whose members do finally attain the "*regina*" stage. Stiasny (1934, p. 361) has pointed out that the latter (i.e., the largest adults) have as a rule been taken well out from any coast, whereas the distribution of the "*dodecabostrycha*" stage makes it likely that "the small stages of Periphylla have their origin on the continental slope or near the coast - - - - and that they are driven into the open sea and sink slowly to greater depths." But such a tendency toward offshore dispersal can hardly explain the absence (or at least great scarcity) of large specimens near Bermuda, for the collection was made at a station as typically oceanic as one could ask; as much so certainly as the Indo-Pacific localities, where the "*regina*" stage has been taken, namely the Galápagos-Cocos Island region, the *Zaca* stations, and the Gulf of Aden (Maas, 1897; Bigelow, 1909; 1928; Vanhöffen, 1902). To what extent such variations may be correlated with seasonal differences between generations in a given region is equally a question for the future.

The most interesting feature of the present series is that it contains two large specimens, respectively about 85 mm. and about 110 mm. in diameter at the level of the coronal furrow, that agree very closely in low-rounded bell, rectangular pedalia, stout tentacular bases and dense pigmentation[8], with the specimens of the "*regina*" stage recently recorded by Stiasny (1934). The fact that in the 85 mm. specimen (alcoholic) the pedalia are rather sharply marked off from the coronal zone but that in the 110 mm. example (in formalin) and also in the largest of all (about 150 mm., fragmentary) they merge insensibly into the latter just as in the *Discovery* examples, is additional evidence (if any were needed) that characters that have been used as specific among medusae may actually represent nothing more than the results of different methods of preservation.

[8] Except where obviously rubbed off.

Atollidae.

Atolla.

Atolla wyvillei Haeckel.

Atolla wyvillei, Haeckel, 1880, p. 488; 1881, p. 113, Pl. 29, Figs. 1-9.

See Broch (1913, p. 13), Browne (1916, p. 203), Bigelow (1928, p. 505; 1938, p. 160), and Stiasny (1934, p. 365), for early synonymy, and Bigelow (1938, p. 162), for a recent summary of distribution.

Material: Stas. 210, 219, 225, 228, 230, 233, 234; 24 specimens, all in hauls from 910-0 meters. The series range in diameter from about 11 mm. to about 95 mm.

This series—all are in more or less fragmentary condition—adds little except by way of confirmation to what is already known of this cosmopolitan bathypelagic medusa. Neither do the records extend the known range, for *A. wyvillei* had already been recorded widespread in the eastern side of the Pacific, not only in low latitudes, but far to the north as well as far to the south of the areas crossed by the *Zaca.*

Among such of the *Zaca* series as are in good enough condition to show the state of the disc, it is more or less furrowed in eleven, but smooth in four, a considerably smaller proportion of smooth-disced than reported near Bermuda (Bigelow, 1938, p. 161), but almost precisely the same proportions as found by Kramp (1924) in the Mediterranean. However, various collections, combined, from the Antarctic (Stiasny, 1934), Mediterranean (Kramp, 1924), and from various localities in the North Atlantic (Broch, 1913; Bigelow, 1928; 1938) have contained about as many of one type as the other (230 smooth, 233 notched).

Unfortunately, the smallest specimens were not in good enough condition to show whether the gonads had appeared, as they commonly do by the time a diameter of 10 mm. is reached. The presence, however, of one specimen of 25 mm., in good condition but showing no trace of gonads, proves that some *Atollas* may reach a considerable size before the sexual organs appear; a retarded development for which no explanation is as yet forthcoming.

DISCOPHORA.

Pelagidae.

Pelagia.

Pelagia noctiluca Forskål

Medusa noctiluca, Forskål, 1775, p. 109.

For summary of synonymy, see Bigelow, 1938, p. 164.

Material: Stas. 219, 227, 230, 233, 234, and Gorgona Island, 34 specimens, about 20 mm. to about 75 mm. in diameter, in hauls at the surface and from 910-0 meters.

All of the smaller specimens are in very fragmentary condition. The two largest, however, (about 65 mm. and about 75 mm. in diameter) are well preserved.

These specimens of this cosmopolitan inhabitant of warm seas all fall well within the known limits of variation of *P. noctiluca.* In fact, it has yet to be proven that this does not apply to every specimen of *Pelagia* from whatever source, that has yet been critically examined. Hence, the general agreement, by recent authors (see especially Kramp, 1924; Stiasny, 1934; Bigelow, 1928; 1938) that the genus, as now known, is monotypic, and that

some designation other than "species" must be invoked to designate the numerous variations as to form and distribution of exumbral nematocyst knobs, on which specific names have been based.

Stomolophidae.

Stomolophus.

Stomolophus illustrates the situation—not uncommon among medusae—where the Linnaean system of classification cannot adequately represent the existing facts, for while the named representatives of the genus differ widely, they are connected by so continuous a series of intermediates in all characters supposedly diagnostic that it appears impossible to define distinct species in the ordinary sense. And, correspondingly, the history of the genus has been one of alternate multiplication and reduction. Thus, Mayer (1910) reduced the five named forms to one species *meleagris* L. Agassiz and one variety of the latter (*fritillaria* Haeckel), while I (Bigelow, 1914) concluded that there was no reason to retain *fritillaria* even as a varietal name. Stiasny (1921; 1922), however, again separated *fritillaria* from *meleagris,* basing the distinction on form of the bell, number of marginal lappets and color, and especially on the form and size of the scapulettes which he considered a reliable anatomical character. More recently, however, he (Stiasny, 1931) has found from examination of excellent preserved specimens from British Guinea and Trinidad, that while extremes of the *"fritillaria"* and *"meleagris"* forms are far apart, all the characters formerly considered specific are so variable that he "der Bigelowischen Ansicht dass nur ein einziger ampla Species von Stomolophus besteht, nicht mehr so ablehnend gegenüber stehe als früher" (Stiasny, 1931, p. 175). The union of *meleagris* and *fritillaria* may therefore be allowed to stand, at least provisionally. Unfortunately, the present series does not afford any basis for the critical study that Stiasny (1922) thinks needful for eventual revision.

Stomolophus meleagris L. Agassiz.

Cephea rhizostoma, Gibbes, 1847, vol. 3, p. 183 (*non* Lamark, 1817).

Stomolophus meleagris, L. Agassiz, 1860, Pl. 14, Figs. 1-8; 1862, p. 138, 151; A. Agassiz, 1865, p. 40; Haeckel, 1880, p. 599; Mayer, 1910, p. 710, Pl. 75, Pl. 76, Figs. 1-3; Bigelow, 1914, p. 240; Stiasny, 1921, p. 170; 1922, p. 57; 1922a, p. 499; Boone, 1933, p. 48, Pl. 10.

Stomolophus agaricus, Haeckel, 1880, p. 599.

Stomolophus fritillaria, Haeckel, 1879, Pl. 35, Figs. 1-9; 1880, p. 598; Von Lendenfeld, 1884, p. 292; Vanhöffen, 1888, p. 31, 42; Stiasny, 1921, p. 170; 1922, p. 55; 1931, p. 175.

Stomolophus meleagris var. *fritillaria,* Mayer, 1910, p. 711.

Stomolophus chunii, Vanhöffen, 1888, p. 31, Pl. 3, Figs. 4, 5, Pl. 4, Fig. 1; Trinci, 1906, p. 1.

Brachiolophus collaris, Haeckel, 1880, p. 597 (juv.).

Material: Sta. 220, surface, 1 specimen about 23 mm. in diameter.

Sta. 219, 540-0 meters, 1 specimen about 40 mm. in diameter.

The larger of these specimens is at about the stage pictured by Mayer (1910, Pl. 75, Fig. 2). They do not add anything of importance to the accounts of the young stages given by him, and by Stiasny (1922a).

Pacific localities of record for *Stomolophus meleagris* had already included the Bay of Panama (Vanhöffen, 1888), the coast of Costa Rica (Haeckel, 1880, as *S. agaricus*), and southern California (Bigelow, 1914).

It was therefore to be expected in the waters traversed by the *Zaca.* The genus is so far known only from the two coasts of America, North and South, in low and mid-latitudes.

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COMPARATIVE RICHNESS OF ZOÖPLANKTON IN COASTAL AND OFFSHORE AREAS OF THE ATLANTIC

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Between our eastern coast and Bermuda lie three zones of water which are of great biological interest because of their extreme contrast: the coastal water, overlying the continental shelf; the "slope" water, which is the area of mixing between the continental slope and the Gulf Stream; and the Sargasso water, of which the Gulf Stream is the western and northern edge. An opportunity to make a comparative investigation of the zoöplankton of the coastal zone and of the zones farther offshore presented itself during the cruises of the research vessel "Atlantis" between Montauk Point, Long Island, N. Y. and Bermuda, which were begun in 1937.

Since the primary object of these cruises was a study of the physical structure of the Gulf Stream and since the ship was working in other localities during the intervals between these cruises, the plankton hauls were necessarily "catch-as-catch-can." Although an extensive network of stations throughout the region which were revisited at frequent intervals would obviously have been desirable, the data available from a single line of stations repeated ten times between October, 1937 and June, 1939 are instructive and raise certain important questions, especially when compared with earlier observations in this area.

Our first objective in the present investigation of the plankton was a comparison of the richness of the coastal and offshore zones. For this purpose four standard stations were located at approximately equal intervals across the coastal water and four more stations were occupied in the slope water beyond (Fig. 1). A ninth station located well within the limits of the Sargasso Sea was established as typifying oceanic water far removed from any influence of the coast. Since the abundance of the plankton was expected to vary within each zone during the course of the season, and since these variations probably would not be the same in different zones, a knowledge of the seasonal cycles of the plankton formed a second objective and one upon which the first necessarily de-

[1] Contribution No. 241.

pended. Furthermore, changes in the general nature and richness of the plankton might occur from year to year. It was therefore proposed to examine our data for annual differences in those months for which

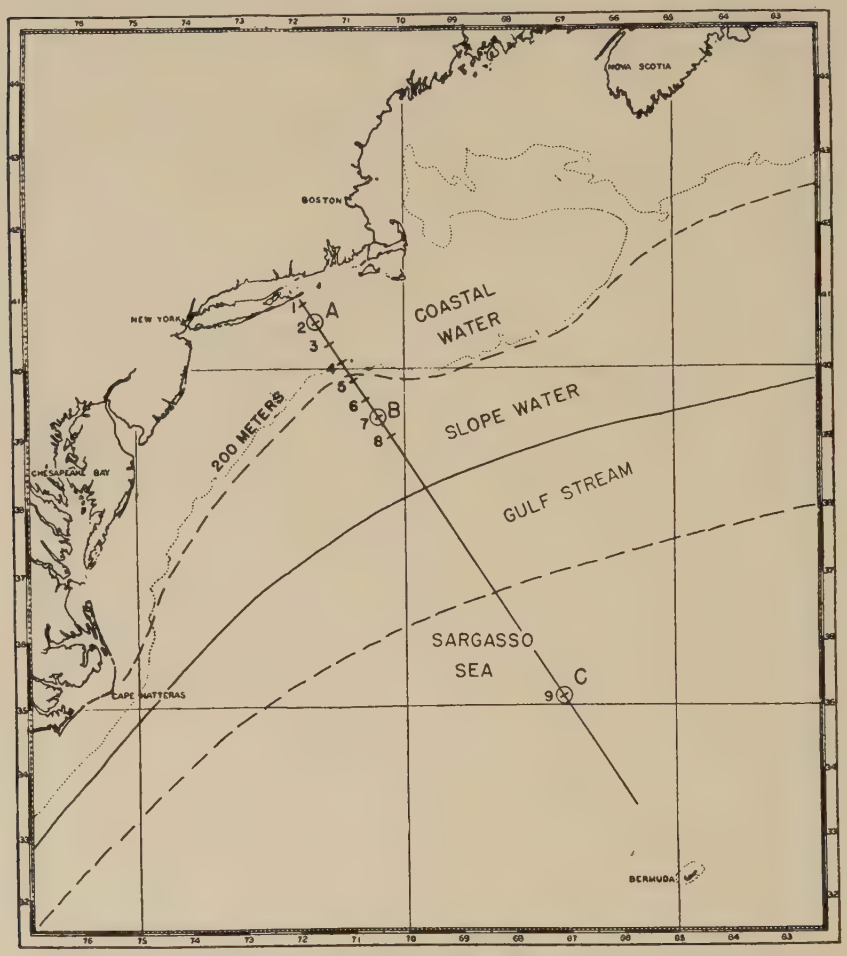

FIG. 1. *The location of stations in three areas of the Atlantic.* Stations 2, 7 and 9, at which certain extra observations were made, have been given the additional designation of *A*, *B*, and *C* respectively. The sharply delineated boundary of the Gulf Stream toward the coast is represented by a solid line; the more indefinite boundary toward Bermuda is indicated by a broken line.

we have observations in two years and also to compare our catches with those made by the U. S. Bureau of Fisheries in the coastal zone during 1929–32, which have been analyzed by Bigelow and Sears (1939).

Hydrography

The coastal area is distinguished from the areas farther offshore first of all by the great and important difference in the depth of the water. At Station 1 the water averaged 44 meters deep, at Station 2(*A*), it averaged 69 meters, and at Station 3 it averaged 85 meters. Station 4 was located just at the brink of the continental slope and the slightly different positions reached on different cruises resulted in depths which varied from 159 meters to 375 meters. The depth in the slope water area was very much greater. At Station 5, located over the steep section of the continental slope, the depth varied from 411 meters to 1,134 meters and at the other stations in this area the water was from 2,000 to 3,000 meters deep. The depth at Station 9(*C*) in the Sargasso Sea averaged 5,100 meters.

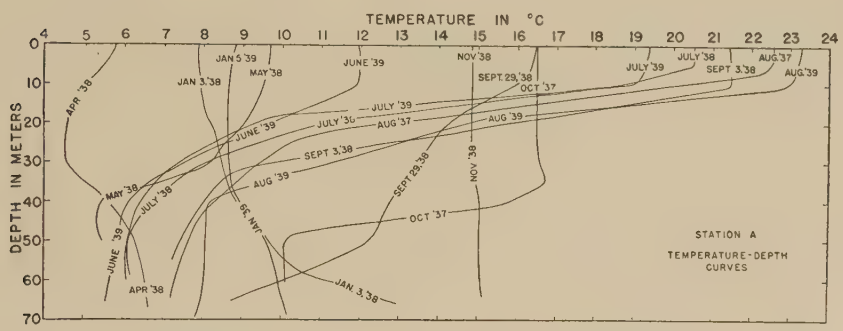

Fig. 2. *Coastal Water*—Seasonal changes in the distribution of temperature with depth at Station 2(*A*).

The currents in the areas under consideration are generally parallel to the coast in their broader aspect. In the coastal zone a slow and intermittent movement of the water down the coast in a southwesterly direction has been detected supplying Stations 1 to 4 with cooler and less saline water than exists offshore. In contrast, the western part of the Sargasso water, i.e., the Gulf Stream, is flowing rapidly in the opposite direction, and at Station 9(*C*) the highest temperatures and salinities were encountered. The slope water is an area of mixing in which intermediate conditions are to be expected. For a complete analysis of the hydrographic situation reference should be made to Iselin (1940). A synopsis of the conditions from the biological viewpoint follows.

At Station 2(*A*), which we may take as typical of the coastal region, the water is found to be completely mixed early in the winter with the result that the temperature is uniform from surface to bottom (Fig. 2).

Cooling continues during the winter until a minimum of about 4° C. is reached in February (Bigelow, 1933). With the arrival of the spring freshets in March and April the salinity of the surface water near the coast is reduced and consequently further vertical mixing with the deeper more saline strata tends to be resisted. At the same time the heat received from the sun, which is increasing at this season, progressively warms the water layers nearest the surface in which the major portion of the radiation is absorbed (Clarke, 1939*a*). Our first spring observation, in April, exhibits the beginning of the vernal warming of the uppermost layers. As this process continues on into the summer, vertical mixing is more and more retarded because of the increasing stability resulting from the greater differences between the surface and the bottom temperatures. Thus, in the late summer of our years, when the temperature at the surface reached the maximum value of about 23° C., water of only about 8° C. existed at the bottom and a sharp thermocline was to be found at mid-depths. During the autumn months cooling at the surface in combination with the stronger winds of that season results in progressively deeper stirring and the consequent further warming of the bottom layers until the winter condition of uniform temperatures is attained. The temperatures observed at Station 2(*A*) indicate that during the period of the present investigation the coastal water was neither abnormally warm nor abnormally cold during any season as judged by the records of previous years (Bigelow, 1933). The salinity at this station varied between 31.2$^0/_{00}$ and 33.2$^0/_{00}$ at the surface and between 32.7$^0/_{00}$ and 33.9$^0/_{00}$ at the bottom during the year. It is doubtful if these relatively slight differences in salt content are of any biological importance. The transparency of the water as measured by the percentage absorption of light per meter ranged from 10 per cent to 14 per cent (Clarke, 1939).

In the Sargasso Sea, as exemplified by Station 9(*C*), the depth to which the seasonal changes in temperature extend is much greater, but the range of temperature variation is much smaller than in the coastal area (Fig. 4). In the Sargasso water a "primary" thermocline extending from about 500 meters to 1100 meters is in existence throughout the year. The upper boundary of this "thermocline layer" represents the lower limit of the stirring action of the wind, and during the winter and early spring months the temperature is found to increase but little from this depth to the surface. Below 800 meters a temperature of less than 15° C. is to be found at all seasons (Iselin, 1936). In our present investigation a minimum temperature for the surface of about 19° C. was observed in April. The vernal warming which follows this winter condition not only raises progressively the temperature of the

surface, but also produces during the ensuing months a "*secondary*" thermocline which is found first at 40 meters but later in the summer at nearly 100 meters. This secondary thermocline disappears again during the late autumn months as a consequence of the deeper stirring of that season. During the present investigation the surface layer attained a maximum temperature of nearly 27° at the end of August. Thus, the seasonal range at the surface amounted to only 8 degrees in contrast to the 15-degree change observed at Station 2(*A*). The salinity in the Sargasso area is remarkably constant: in the present investigation all observations down to 300 meters were confined between 36.1 and 36.7$^0/_{00}$. The absorption of light by the water, which has been found

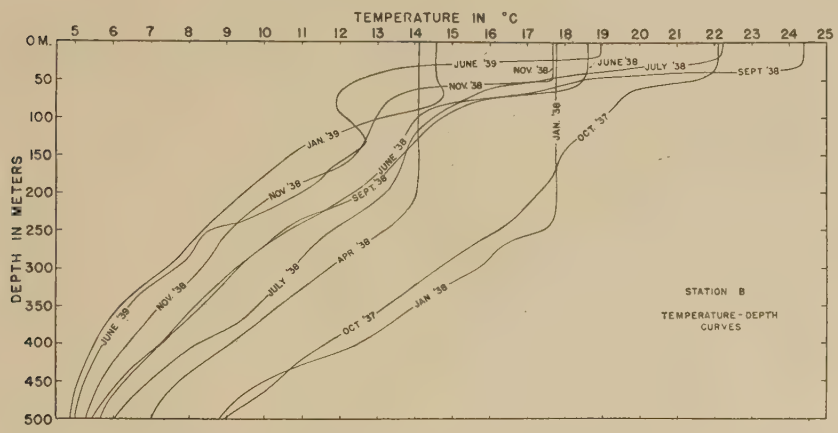

FIG. 3. *Slope Water*—Seasonal changes in the distribution of temperature with depth at Station 7(*B*).

to take place at an extremely low rate in this part of the ocean, varied between 4.2 per cent and 6.6 per cent per meter (Clarke, 1939*a*).

At Station 7(*B*), in the middle of the slope water zone, the hydrographic conditions were generally intermediate between those obtaining in the coastal and in the Sargasso zones. They are subject, however, to very large fluctuations, especially in the upper 200 meters, because nearly pure coastal water or nearly pure Sargasso water may be present at the station in question, and on our various visits all degrees of mixing were encountered. The seasonal temperature cycle is of the same nature here as in the Sargasso zone, but the main thermocline layer is shoaler, extending in the present case from about 250 meters to 600 meters and temperatures are generally lower (Fig. 3). Thus, at Station 7(*B*) the seasonal change of 10 degrees which was observed for the

surface water ranged from 14° C. to 24° C. The salinity and the transparency of the slope water similarly veer toward values characteristic of the coastal water or of the Sargasso water, according to the proportions in which those two types are present as has been discussed in detail elsewhere (Clarke, 1939*a*).

Collection and Measurement of Plankton [2]

Our present plankton studies are based primarily on a pair of "oblique" hauls (one shallow and one deep) made with an open scrim

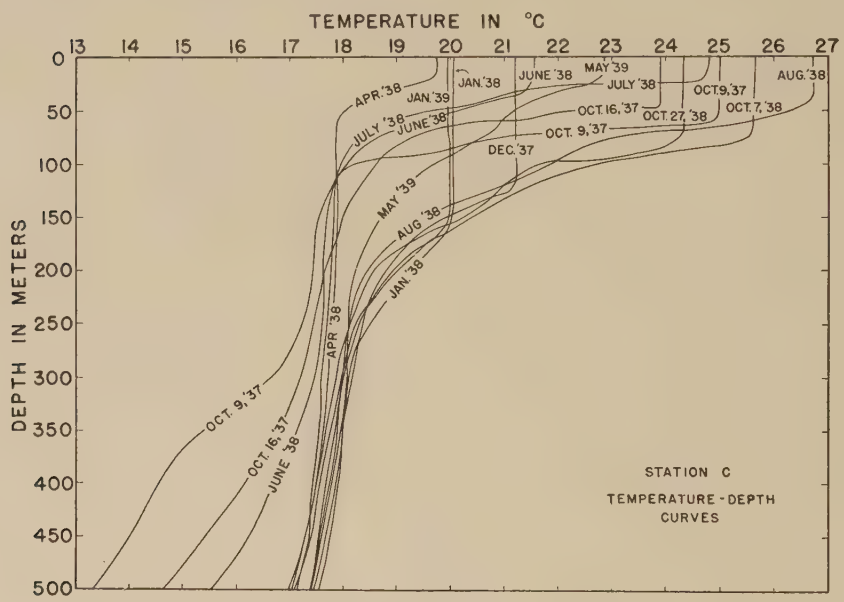

Fig. 4. *Sargasso Sea*—Seasonal changes in the distribution of temperature with depth at Station 9(*C*).

net (10 strands/cm.) at each of the nine stations shown in Fig. 1. For the shallow haul the net was lowered to 25 meters in most cases (but to 50 meters at Stations 7(*B*) and 9(*C*)) and hauled in at the rate of 5 meters every 5 minutes (5 meters every 2 minutes from 50-meter level), while the ship was steaming at 1½ to 2 knots. For the deep haul, the net was lowered to the bottom at Stations 1–4, to about 275 meters at Stations 5–8, and to about 800 meters at Station 9, and then, while steaming, hauled up to 25 meters (or to 50 meters) at such a rate that

[2] Carried out by Mr. Dean F. Bumpus, Biological Technician for the Woods Hole Oceanographic Institution.

the total towing period consumed about 30 minutes. In this way a picture was obtained of the plankton in the superficial stratum above the summer thermocline and of the plankton in the underlying strata from which some biological relationship with the surface might be expected.

At Stations *A*, *B*, and *C*, located within the three areas under consideration, additional observations were undertaken to supply further detail to the biological picture. Shallow and deep hauls with a stramin net (either 1½ or 2 meters in diameter) were made at these stations for the collection of the larger and less abundant elements of the population which might not be sampled adequately by the smaller nets. In these hauls the same depths and general procedure were used as for the work with the scrim nets. When weather permitted, both the scrim and the stramin nets were rigged for closing (Leavitt, 1935, 1938) as a check on the deductions from the open net hauls as to the exact nature of the vertical distribution of the zoöplankton. Those elements of the zoöplankton which were too small to be retained by the relatively coarse scrim net were investigated at these stations by means of shallow and deep oblique hauls with a No. 10 (43 strands/cm.) silk net 30.5 cm. in diameter. In addition, phytoplankton material was obtained at the three key stations, and in some cases at the intervening stations as well, from water samples and from hauls with No. 20 silk nets, and was turned over to Dr. Lois Lillick and to Dr. James B. Lackey for study.

For the whole of the cruise of May 29–June 5, 1938, for the major part of the cruise of July 9–17, 1938, and in certain other cases, hauls were made with plankton samplers provided with No. 10 silk nets or with No. 2 (21 strands/cm.) silk nets. The plankton sampler is a newly developed instrument consisting of a tube 12.7 cm. (5 inches) in diameter to the end of which a conical net is attached. The tube is provided with a shutter and contains a volume meter which records the amount of water which has actually passed through the net (Clarke and Bumpus, 1939). Tests reported by Winsor and Clarke (1940) indicate that a net with a diameter as small as 12.7 cm. is as reliable as a net 75 cm. in diameter. The operation of the samplers, in their earlier design, was interfered with by the unusual abundance of salpae which were encountered at a large number of the stations (see below), and it was found that the towing periods employed in the barren offshore waters were not long enough to yield a catch of satisfactory size for detailed analysis. Nevertheless, the work with the plankton samplers provides us with a certain number of cases from which the absolute density of the plankton under various circumstances can be deduced with precision. The plankton sampler hauls therefore comprise a valuable adjunct to the hauls with nets of the more usual type.

The abundance of the zoöplankton taken in the hauls has been determined in all cases by means of volume measurement and, in the case of certain species, by enumeration. The volume was measured by displacement, since Bigelow and Sears (1939) have recently called attention to the superiority of this procedure over the settlement method. The whole catch was placed in a graduated cylinder and the total volume noted. The catch was then poured through netting of the same (or of smaller) mesh than that of the net used in making the catch and allowed to stand until dripping had practically stopped. The volume of water thus separated was then measured and subtracted from the total volume to obtain the volume of the plankton alone. In those cases in which sagittae, salpae, or coelenterates formed an important fraction of the total catch, these elements were picked out and measured separately. The remaining plankton, composed chiefly of copepods and euphausids but containing also some amphipods, limacina, etc., has been designated as the "crustacean" fraction of the haul.

The species in the present study which were enumerated were the important copepods, *Calanus finmarchicus* and *Centropages typicus*. Separate count was kept of the males and females and, in the case of *Calanus,* of the developmental stages as well. The method employed for sub-sampling and for counting[3] was that described by Winsor and Clarke (1940).

Variability in Volume and in Type of Plankton

The volumes of all the hauls made with the scrim net in the present investigation are presented in Tables I and II, which give respectively the values for the "total plankton" and for the "crustacean plankton." It will be observed that the amounts of plankton caught are extremely variable, ranging from a maximum of 3,060 cc. to a minimum of 1 cc. in the case of the total plankton and from 225 cc. to 1 cc. for the crustacean plankton. Very considerable changes in volume were often encountered at neighboring stations, as was also observed by Bigelow and Sears (1939). This situation immediately raises the question of the reliability of single hauls. Fortunately there is available a statistical study of the variation to be expected from just such material as is dealt with here in the report of Winsor and Clarke (1940). These investigators found that in the case of oblique hauls with a 75 cm. scrim net, the standard deviation of the haul-to-haul variation was about 20 per cent of the mean. It is therefore obvious that the major portion, at

[3] Several small hand "counting machines" mounted on a board were found to be extremely useful for keeping count of the various categories observed through the microscope.

Table 1

Total plankton. Volume in cc. of plankton of all types taken with 75 cm. scrim net. Volume reduced to 30-minute haul. Hauls in italics taken between sunset and sunrise. *S* = shallow. *D* = deep (see text).

	Station	Depth	1938 Jan. 2–7	1939 Jan. 5–10	1938 Apr. 6–13	1939 May 28–June 3	1938 July 9–17	1938 Aug. 28–Sept. 3	1938 Sept. 29–Oct. 8	1937 Oct. 2–9	1937 Oct. 17–21	1938 Oct. 27–Nov. 3	Average
Coastal Water	1	*S*	*26*	—	—	62	85	8	—	*45*	—	*178*	
		D	*36*	—	—	64	*100*	15	—	*150*	—	*100*	
	2(*A*)	*S*	*20*	—	*24*	*84*	107	220	35	*81*	*20*	400	
		D	*26*	—	4	*55*	214	970	—	*115*	*27*	114	
	3	*S*	31	*4*	40	*162*	—	*83*	*660*	265	—	*190*	
		D	20	*7*	—	*222*	3060	*202*	*220*	262	—	*129*	
	4	*S*	5	—	170	22	—	*720*	*54*	225	—	*115*	
		D	5	—	—	94	—	*590*	*82*	308	—	*53*	
	Average	Shallow	21	4	78	83	96	258	249	154	20	221	118
	Average	Deep	22	7	4	109	1125	444	151	205	27	99	220
	Combined	(Weighted)	22	7	23	103	868	398	176	192	25	129	194
Slope Water	5	*S*	*2*	*22*	9	17	—	—	—	*435*	—	—	
		D	10	*40*	*40*	22	—	—	—	*200*	—	—	
	6	*S*	*31*	9	*17*	60	—	12	30	*82*	—	40	
		D	*13*	11	*43*	254	—	20	20	*111*	—	26	
	7(*B*)	*S*	7	16	*32*	*515*	—	5	*40*	*130*	75	*145*	
		D	*6*	38	*8*	*54*	—	18	*55*	*155*	22	*32*	
	8	*S*	*11*	*375*	*5*	31	—	*85*	9	80	—	60	
		D	*11*	*113*	*10*	44	—	*100*	—	48	—	53	
	Average	Shallow	13	106	16	156	—	34	26	182	75	82	77
	Average	Deep	10	51	25	99	—	41	38	129	22	37	50
	Combined	(Weighted)	10	56	24	104	—	40	37	134	27	41	52
Sargasso Sea	9(*C*)	50–0 m.	*55*	9	*33*	*15*	—	*9*	*25*	*45*	*10*	*27*	29
		100–50	—	14	*53*	*43*	—	*38*	*27*	—	*5*	*12*	27
		500–100	*5*	*18*	*13*	—	—	*6*	*9*	*7*	*4*	*5*	8
		900–500	*4*	—	*5*	—	—	*1*	*9*	—	*6*	*5*	5
	Combined	(Weighted)	*7*	17	13	29	—	6	11	11	5	7	12

Table II

Crustacean plankton. Volume in cc. of plankton after removal of major portion of sagittae, salpae and coelenterates taken with 75 cm. scrim net. Volume reduced to 30-minute haul. Hauls in italics taken between sunset and sunrise. *S* = shallow, *D* = deep (see text).

	Station	Depth	1938 Jan. 2–7	1939 Jan. 5–10	1938 Apr. 6–13	1939 May 28–June 3	1938 July 9–17	1938 Aug. 28–Sept. 3	1938 Sept. 29–Oct. 8	1937 Oct. 2–9	1937 Oct. 17–21	1938 Oct. 27–Nov. 3	Average
Coastal Water	1	*S*	*26*	—	—	62	37	8	—	*38*	*20*	*56*	
		D	*20*	—	—	64	*71*	—	—	*126*	*27*	*50*	
	2(*A*)	*S*	*20**	—	*15*	*84*	91*	52	14	*46**	—	50	
		D	*26**	—	4	*55*	214	156	—	*62**	—	48	
	3	*S*	24	*4*	1	*162*	—	*45*	*0*	85	—	*74*	
		D	20	*7*	—	*126*	68	*47*	*22*	86	—	*52*	
	4	*S*	—	—	84	11	—	*135*	*10*	25	—	*70*	
		D	4	—	—	73	—	*225*	*22*	103	—	*16*	
	Average	Shallow	23	4	33	80	64	60	12	48	20	62	41
	Average	Deep	18	7	4	79	118	143	22	94	27	42	50
	Combined	(Weighted)	19	6	11	79	104	122	19	82	25	47	50
Slope Water	5	*S*	*2*	*18*	8	9	—	—	—	*21*	—	—	
		D	10	*40*	*40*	11	—	—	—	*12*	—	—	
	6	*S*	*16*	9	*17*	15	—	1	12	*45*	—	4	
		D	*8*	11	*39*	18	—	16	*7*	*39*	—	11	
	7(*B*)	*S*	5	13	*32*	*72**	—	3	*14**	*45*	4	*68**	
		D	*6*	25	*8*	*43**	—	14*	10*	*23*	12	*16**	
	8	*S*	*7*	*28*	*3*	1	—	*76*	9	15	—	14	
		D	*10*	*56*	*10*	9	—	—	—	20	—	15	
	Average	Shallow	8	17	15	22	—	27	12	32	4	29	18
	Average	Deep	9	33	24	22	—	15	9	24	12	14	18
	Combined	(Weighted)	9	32	23	22	—	16	9	25	11	15	18
Sargasso Sea	9(*C*)	50–0 m.	*25**	5	*19**	*10*	—	*6*	*16*	*44*	*5*	*21*	17
		100–50	—	10	*42**	*16*	—	*24*	*19*	—	*4*	*6*	17
		500–100	*3*	*13*	*5*	—	—	*4*	*5*	*6*	*3*	*2*	5
		900–500	*4*	—	*4*	—	—	*1*	—	—	*4*	*2*	3
	Combined	(Weighted)	5	12	7	13	—	4	8	10	4	4	7

* Occasions on which the small copepods in the corresponding No. 10 silk net haul amounted to > 5 cc.

least, of the fluctuation in volume observed in the present case is real and not due to errors of observation.

A further question, and one more difficult to answer, is the extent of the area over which each haul may be taken as representative. Previous plankton studies have shown that the dispersal pattern of the population in each situation must be investigated individually. For this purpose a closer network of stations must be arranged than was possible in the present case and strictly quantitative hauls employed, as, for example, through the use of registering plankton samplers (Clarke and Bumpus, 1939) or of a continuous plankton recorder (Hardy, 1936).

TABLE III

Comparison of three sets of 30-minute hauls with 75 cm. scrim net at Station 2(*A*) as a sample of variability.

	Oct. 2, 1937 Closing net (Day Haul)	Oct. 2, 1937 Open net (Day Haul)	Oct. 3, 1937 Open net (Night Haul)
Total volume (cc.)			
Shallow	33	140	45
Deep	46	127	150
Total	79	267	195
Crustacean volume (cc.)			
Shallow	33	14	38
Deep	46	58	126
Total	79	72	164
Calanus stage IV			
Shallow	250	234	400
Deep	1,940	3,000	6,500
Calanus stage V			
Shallow	500	117	900
Deep	2,500	7,200	16,200
Centropages ♂			
Shallow	8,500	5,050	5,800
Deep	21,600	24,600	15,500
Centropages ♀			
Shallow	22,200	9,800	14,800
Deep	51,000	41,100	28,500

In the present investigation two bits of evidence exist on the variability of hauls closely spaced in time and in position. At Station 2(*A*) on October 2, 1937, a pair of hauls with the closing scrim net was followed immediately with a pair of hauls of the same type with the open

net and in addition the open net hauls were repeated at this station on the following day (Table III). In each of the categories compared in this table, the largest volumes are found to be three or four times greater than the smallest volumes. In those cases in which numbers of individuals are compared, the differences are greater. Evidently the variations of the separate groups considered tend to cancel out when volumes of mixed species are compared.

A more extensive study of the variation encountered within a small area was made on May 17–18, 1938, when hauls were made with the scrim net and with the plankton samplers (No. 2 silk) at Station 2(*A*) and at four stations located about 10–15 miles distant to the south, east, north, and west respectively of Station 2(*A*). The work with the plankton samplers was repeated at Station 2(*A*) on May 30, 1938. The variation in the volumes of these hauls and in the number of *Calanus* in copepodid stages IV and V may be observed in Table IV. Not only did the volumes fluctuate irregularly from station to station with differences as great as 10-fold in extreme cases, but also it is seen that the variations in the shallow stratum did not conform to those in the deeper layers. As in the previous case, the fluctuations in the actual numbers of *Calanus* are even greater than the changes in volume. The histogram plots of Figs. 5 and 6 reveal the very great extent to which the species composition of these hauls varies. The diagrams show, for example, that at some of the stations in this group *Calanus* was the dominant form in the catches of the scrim net, whereas at other stations small medusa were by far the most abundant organisms. Similarly, in the case of the hauls with the plankton samplers, the proportion in which each type of animal is represented varies tremendously—in one haul *Calanus* takes the lead, in other hauls *Evadne, Pseudocalanus,* or medusae greatly outnumber all the other forms.[4] In view of this far-reaching irregularity in distribution, it is essential that the number of stations occupied be as large as possible and that all hauls within each area be combined in suitable ways before any conclusions be attempted in regard to relative richness. In the following discussions, therefore, *average values* will be considered for the most part for each of the areas under consideration.

In all the foregoing data it is evident that the variability of "crustacean volume" is much less than that of the "total volume." We may conclude, therefore, that fluctuation in the abundance of salpae, sagittae, coelenterates and other non-crustacean elements are largely responsible for the great irregularities of Table I. The more uniform complexion of the hauls during the winter months is largely due to the fact that the

[4] The dominant species were not expected to be the same as in the scrim net hauls since the netting in the plankton samplers was of smaller mesh.

TABLE IV

Comparison of scrim net hauls at Station 2(*A*) and at four surrounding stations 10–15 miles distant on May 17–18, 1938, and comparison of plankton sampler hauls for the same stations and for Station 2(*A*) on May 30, 1938.

	Scrim net (75 cm. diameter). Vol. or no. per 30 min. haul					Plankton sampler. Vol. or no. per m³. of sea water					
	Sta. 2(*A*) May 17, '38 (Day Haul)	Sta. 2(*A*)–*S* May 17, '38 (Night Haul)	Sta. 2(*A*)–*E* May 18, '38 (Night Haul)	Sta. 2(*A*)–*N* May 18, '38 (Day Haul)	Sta. 2(*A*)–*W* May 18, '38 (Day Haul)	Sta. 2(*A*) May 17, '38 (Day Haul)	Sta. 2(*A*)–*S* May 17, '38 (Night Haul)	Sta. 2(*A*)–*E* May 18, '38 (Night Haul)	Sta. 2(*A*)–*N* May 18, '38 (Day Haul)	Sta. 2(*A*)–*W* May 18, '38 (Day Haul)	Sta. 2(*A*) May 30, '38 (Night Haul)
Total volume (cc.)											
Shallow *	57	119	23	112	75	1.02	.94	.31	.71	.76	.34
Intermediate †						.48	.56	1.08	.29	.74	—
Deep ‡	21	120	112	13	26	1.90	.90	.96	1.02	1.15	—
Crustacean volume (cc.)											
Shallow	57	119	18	28	8						
Intermediate						—	—	—	—	—	—
Deep	21	105	25	11	26						
Calanus stage IV											
Shallow	31,500	29,400	7,550	12,700	1,900	785	161	202	475	310	87
Intermediate						84	218	111	100	167	32
Deep	4,950	26,700	7,500	1,940	2,420	69	27	218	101	96	66
Calanus stage V											
Shallow	16,300	22,200	4,580	7,750	2,050	108	75	24	35	38	73
Intermediate						42	175	174	44	53	45
Deep	6,400	32,800	10,500	4,750	5,500	57	113	115	82	32	10

* "Shallow" for both scrim net and plankton sampler indicates oblique haul from 25 meters (wire out) to surface.
† "Deep" for scrim net indicates oblique haul from bottom to 25 meters; for plankton sampler, bottom to 50 meters.
‡ "Intermediate" for plankton sampler indicates oblique haul from 50 meters to 25 meters.

plankton at that season consisted mainly of crustacea, particularly at stations toward the coast. Salpae, which were unusually abundant during the present investigation, not only in the slope water, where they are known to be common, but also in the coastal water, most frequently accounted for the difference between the crustacean volume and the total

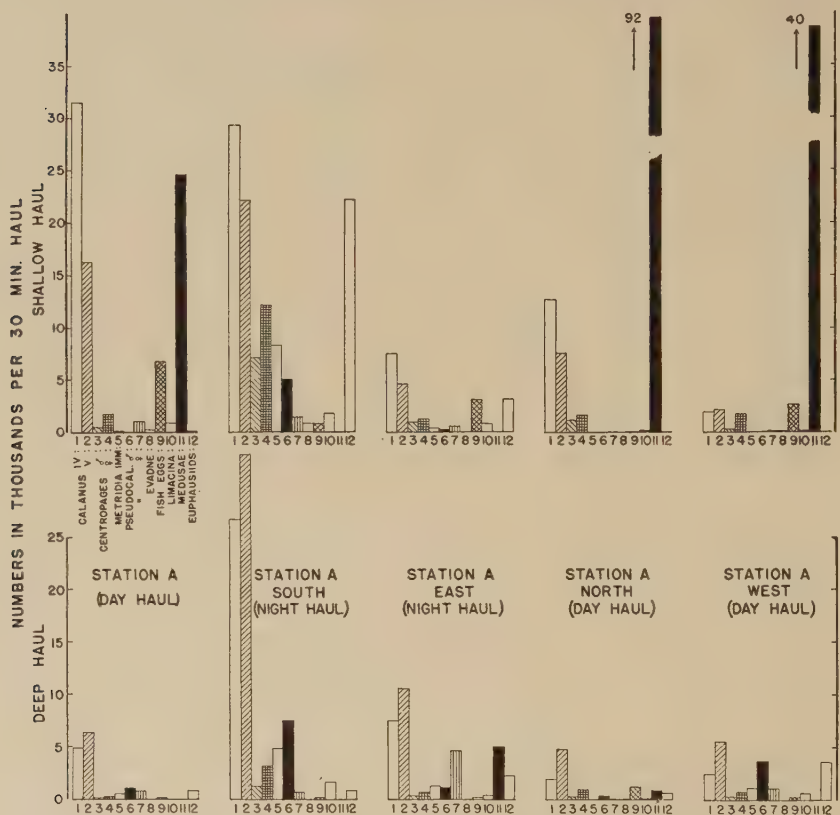

FIG. 5. Variation in composition of scrim net hauls at Station 2(*A*) and at four surrounding stations 10–15 miles distant on May 17–18, 1938.

volume. Indeed, in every case but one, values greater than 200 cc. were attributable to the presence of salpae.

The separation of the crustacea from the other types of animals provides us with an approximate division of the plankton into (1) the "more nutritive" forms which are known to be prominent in the diet of the important fish of the region and (2) the forms of little or no nutritional value. This method of subdivision conforms to that adopted by Bigelow and Sears (1939) with the exception that these authors

included the sagittae with the crustacea as being of considerable food value. Since in the present investigation sagittae were relatively rare (occurring chiefly in the winter months) and in no case amounted to more than 50 cc., it appears legitimate in this case to regard our "crustacean volumes" as comparable to the category of "more nutritive forms" dealt with by Bigelow and Sears. The volumes appearing as "crustacean plankton" (Table II) may thus be accepted as a rough index of

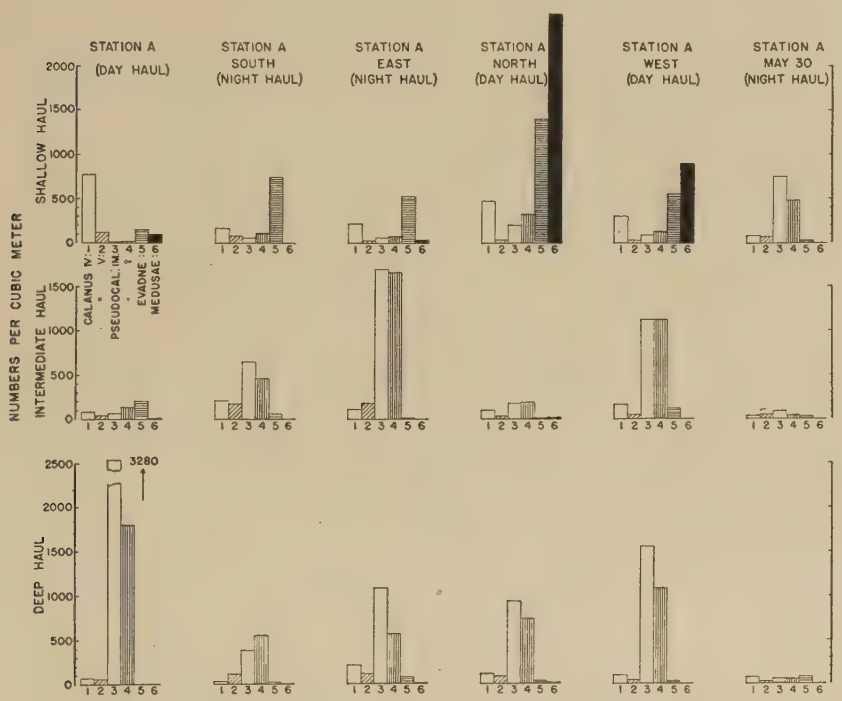

FIG. 6. Variation in composition of plankton sampler hauls at Station 2(*A*) and at four surrounding stations 10–15 miles distant on May 17–18, 1938 and at Station 2(*A*) on May 30, 1938.

the abundance of food for plankton-feeding fish within the bounds of the present investigation.

Hauls made with the large stramin nets and with smaller nets of No. 10 silk at Stations *A, B* and *C* were examined for the possible occurrence of important elements of the plankton which were either too large and active or too small to be caught adequately by the scrim nets. The volumes of plankton taken by the stramin nets were of the same order of magnitude as those taken by the scrim nets although the amount of water

filtered by the former type of net was very much greater. Evidently the loss of the types of plankton which slip through the meshes of the stramin net is relatively greater than the additional number of active species which are taken by this net but missed by the scrim net. A certain portion of larger crustacea were found in the stramin net hauls but the bulk of the more voluminous catches consisted of salpae, as was the case with the scrim net hauls. At the other end of the size scale there exist members of the plankton community which are not retained even by the scrim net. Hauls made simultaneously with scrim and with fine silk nets of the same size (unpublished records) have shown that in situations where small copepods (such as *Pseudocalanus, Paracalanus,* or immature *Centropages*) are abundant, the catch of the silk net may be several times greater than that of the scrim net. Under such circumstances the volumes of scrim net hauls alone would greatly underrate the richness of the plankton. However, the hauls with the No. 10 silk nets indicate that the smaller animals were not generally abundant during the present investigation. Amounts of crustacean plankton greater than 5 cc. were taken in these nets on only three occasions at Station *A,* four occasions at Station *B,* and two occasions at Station *C,* as indicated in Table II. Volumes greater than 10 cc. were taken only at Station *A,* once in July and once in October. We may conclude, therefore, that for the investigation as a whole the scrim net sampled the major portion of the population and that the hauls with this net are a satisfactory index to the richness of the animal plankton.

Distribution of Plankton by Volume

Vertical Distribution

The vertical distribution of the plankton in the three areas may be ascertained from Tables I and II, in which the volumes taken in the "shallow" and "deep" hauls at each station are compared. Since the time of visiting each station fell at various hours of the day or night, the influence of any diurnal vertical migrations on the picture presented must be considered (Clarke, 1933 and 1934). For this purpose the hauls made during the day between sunrise and sunset have been differentiated in the tables from those made during the night.

For the total plankton in the coastal area, the deep hauls were greater than the surface hauls in 62 per cent of the stations occupied during daylight hours and in 67 per cent of the night stations. In the slope water area the deep hauls were greater in 58 per cent of the day stations and in 54 per cent of the night stations. These figures indicate that the vertical distribution of the plankton as a whole is essentially the same by day or

by night in these areas. When the crustacean plankton is considered separately, it is found that in the coastal area the deep hauls were greater than the surface hauls in 75 per cent of the day hauls and in 60 per cent of the night hauls. In the slope water area the deep hauls were greater in 100 per cent of the day hauls but in only 42 per cent of the hauls made during the night. These figures make it clear that a diurnal vertical movement of the crustacea was taking place in the slope water area and to a lesser extent in the coastal water. Unfortunately, all the hauls except two at Station 9(*C*) in the Sargasso Sea fell during the night period and consequently we are unable to state whether the distributional picture would have been different had a significant number of day hauls been made (cf. Waterman, Nunnemacher, Chace, and Clarke, 1939).

For a *general* consideration of vertical distribution in the coastal area the day and night hauls may be averaged since the differences between them are not great. The average volume of the total plankton of all the shallow hauls in this area was 118 cc. and of the deep hauls was 220 cc. If, however, the cruise of July 9–17, 1938 is omitted because of the presence in one haul of an exceptionally large number of salpae, these values become 120 cc. for the surface and 119 cc. for the deep hauls. The average volumes of the crustacean plankton in this area were 41 cc. for the shallow hauls and 50 cc. for the deep. In the slope water area day and night hauls may similarly be averaged for a general consideration since there are an equal number of each. In this area the total plankton averaged 77 cc. for the shallow hauls and 50 cc. for the deep hauls and the crustacean plankton averaged 18 cc. for the hauls at both levels. We may therefore conclude that for the year as a whole no important difference existed in the richness of the plankton in the upper and lower strata in these two areas. At the station in the Sargasso Sea, the volume of the crustacean plankton and of the total plankton was about the same in the uppermost 50 meters of water as it was in the stratum from 100 meters to 40 meters. But in every case except one (in which the shallower hauls were made during the day) the plankton was more abundant above 100 meters than in the deeper strata.

Seasonal Distribution

In order to obtain a value characteristic of the whole population in each area for each season and to eliminate any localized influence which diurnal migration might have on the distributional picture, we may combine the shallow and deep hauls for each of the cruises. It must be remembered, however, that at no station was it practicable to allow the net to fish down to the very bottom and at the deeper stations a considerable

stratum remained unsampled. Although the possibility exists that a population of some importance might thus have been missed, we have no evidence that the plankton just over the bottom on the continental shelf is significantly more abundant than in the water nearer the surface. In the oceanic areas with which we are concerned here, Leavitt (1938) found that the macrozoöplankton was considerably less rich below 1,000 meters than above that depth. In combining the average hauls at the two levels, the deep haul has been weighted in proportion to the relative thickness of the stratum through which it was towed as compared with the shallow haul. The combined average is thus a characteristic index of the whole depth of water sampled.

Considering first the coastal area, we find that the plankton as a whole reached its lowest ebb during the winter in both 1938 and 1939 (Table I). By the end of May, the volume of the catches was greatly increased and in July and August the plankton bulked twenty to forty times as large as it did in the winter, the augmentation being most pronounced toward the outer edge of the continental shelf where the salpae were especially abundant. Early in October the haul volumes were of about the same size as in May, but a decline appeared by the middle of October in 1937 and at the end of that month in 1938 and the population presumably continued to shrink until the following January. The magnitude of this seasonal increase in volume appears to be considerably greater than that reported by Bigelow and Sears (1939) for even their best plankton years, but the contrast is largely due to the fact that our values at the beginning of the year are lower. Our summer volumes generally did not attain the size of those found by the earlier workers. In the present investigation the volumes of the crustacean plankton (Table II) followed much the same course as did the total plankton, since smallest values were taken in the winter and largest values during July and August. It is of interest to note that the crustacean element was still at a low ebb in April, and that in 1938 a period of scarcity occurred early in October followed by increased volumes at the end of the month, whereas in 1937 no prominent decline occurred until the middle of October.

In the slope water area little, if any, information existed previously on seasonal variation in richness. From our present data we may observe that although the average values for the total plankton did not vary over as great a range as was the case in the coastal area, and although the fluctuations were irregular, nevertheless, the hauls of smallest volume occurred during the colder part of the year and values as much as ten times greater were found in May and October. In the case of the crustacean plankton, however, the largest volume of the year was less than four times the smallest volume and both high and low values oc-

curred at all seasons. Cognizance should also be taken of the fact that the average volumes of both the total plankton and of the crustacea differed widely in January, 1938 from those found in January, 1939 and a similar lack of agreement occurred between the values of early October, 1937 and 1938.

At our station in the Sargasso Sea there is even less evidence of a seasonal fluctuation in the richness of the plankton. As far as the total plankton is concerned, the largest average volumes were obtained in January, 1939, in April and in May–June, but volumes of almost equal magnitude were taken in September and October. Furthermore, since the individual hauls vary so greatly in size, we probably would not be justified in designating any one season as a period of increased plankton abundance. The same conclusion applies to the crustacea since the volume of this fraction of the plankton also varied irregularly, and since the highest value recorded was only about four times the lowest. It thus appears that among the three areas investigated indication of a significant seasonal change in richness for the total plankton was found only in the coastal and slope water zones and for the crustacean plankton only in the coastal area. Especially noteworthy was the occurrence of seasonal differences of greater magnitude than was suspected heretofore.

Regional Distribution

If the plankton volumes for all seasons are now combined, a basis is formed upon which a rough quantitative comparison may be made for the first time of the average differences in the richness of the several areas. This operation yields a grand average of 194 cc. for the volume of the zoöplankton of all types taken with the 75 cm. scrim net in the standard 30-minute haul in the coastal area. This figure is nearly four times as great as the average value of 52 cc. for the slope water area, which in turn is about four times the magnitude of the grand average of 12 cc. for our station in the Sargasso Sea (Table I). The average volumes for the crustacean plankton were 50 cc., 18 cc., and 7 cc. for the coastal area, the slope water area and the Sargasso Sea respectively (Table II). The abundance of the crustacea thus exhibited the same downward trend in passing offshore as was observed for the total plankton although the differences were only 2 or 3-fold in this case. Since we cannot yet make an adequate statement concerning the growth rate of the animals considered here, or rate of replenishment of the populations, no general conclusion can be drawn concerning the "productivity" of these areas in a broader sense. However, the present investigation does clearly indicate the existence in the coastal area of a "standing

crop" which, on the average, significantly exceeds that characterizing the water farther offshore.

Variation in Abundance of Calanus and Centropages

The foregoing study of the variations in volume of plankton in the three oceanic areas under consideration has been supplemented by a numerical analysis of the fluctuations in two individual species of prominence—the copepods, *Calanus finmarchicus* and *Centropages typicus*. The variations in the abundance of Calanus are presented graphically in Fig. 7, where all stages which were caught by the net (copepodid stages IV and V and adults) have been added together and the shallow haul and deep haul (weighted) have been combined for each station.

It is clear from the graph that by far the major portion of the *Calanus* population is to be found in the coastal area, although a small number of this species was taken at Stations 6 and 7. No *Calanus finmarchicus* were found at Station 9 in the Sargasso Sea. The fact that the richest hauls were made at Stations 2, 3 and 4 with only moderate numbers at Station 1 is consistent with the distributional picture for this species presented by Bigelow and Sears (1939, Fig. 23). *Calanus* reached its greatest abundance during April, June, and July in the present survey as was also the case for the average of the years 1929–32 in the northern half of the area studied by Bigelow and Sears. At the station in the western entrance to Vineyard Sound occupied by Clarke and Zinn (1937), *Calanus* was similarly found to be most numerous from April to August. It therefore seems well established that the spring and summer months are the seasons at which *Calanus* comes into prominence as a member of the plankton community in this region.

The subdivision of the *Calanus* population into its sex and age groups at the stations in the coastal area throughout the year may be scrutinized in Fig. 8. The histograms here presented show that the great variability which characterized both the volumes and the species composition of the hauls also extends to the subdivisions within a single type of animal. Not only do the sex and age groups differ among the several stations on the same cruise, but in addition we find variations from year to year. Nevertheless, certain generalities appear. Copepodid stage V was the most numerous group for the investigation as a whole and particularly so during the autumn and winter months, but stage IV became prominent in May and June and in September. The occurrence of the adult females, which were the next most abundant, was rather irregular although there was some indication that this group was more usual near shore than at Stations 3 and 4. The fact that out of the total number

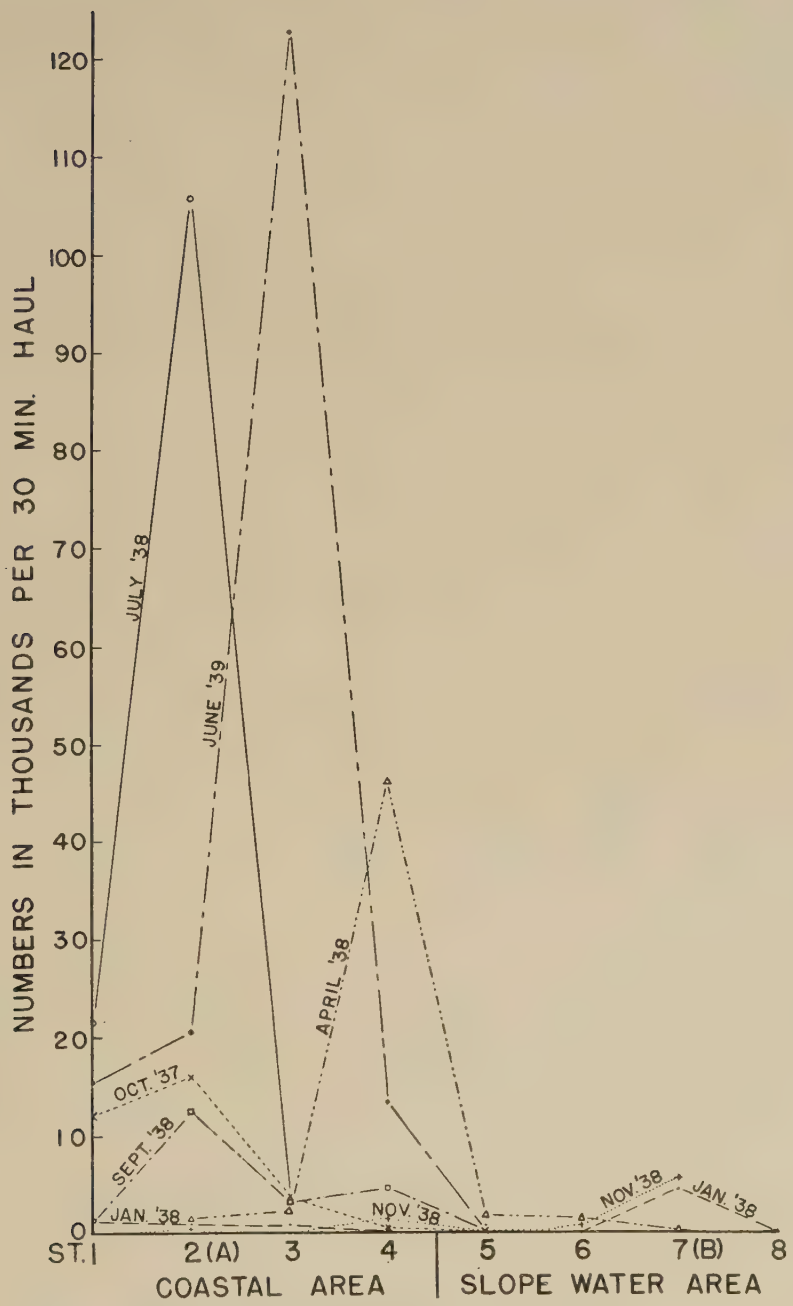

FIG. 7. *Variation in abundance of Calanus finmarchicus (all stages) throughout the year.* Shallow haul and deep haul (weighted) have been combined. Numbers of animals on cruise of Sept. 29–Oct. 2, 1938, too low to appear in graph. On cruise of Jan. 5–9, 1939, *Calanus* taken at Station 5 only.

of hauls adult males of *Calanus* were found only in January and in May and June agrees very closely with the observations at the station occupied several years earlier by Clarke and Zinn (1937). These investi-

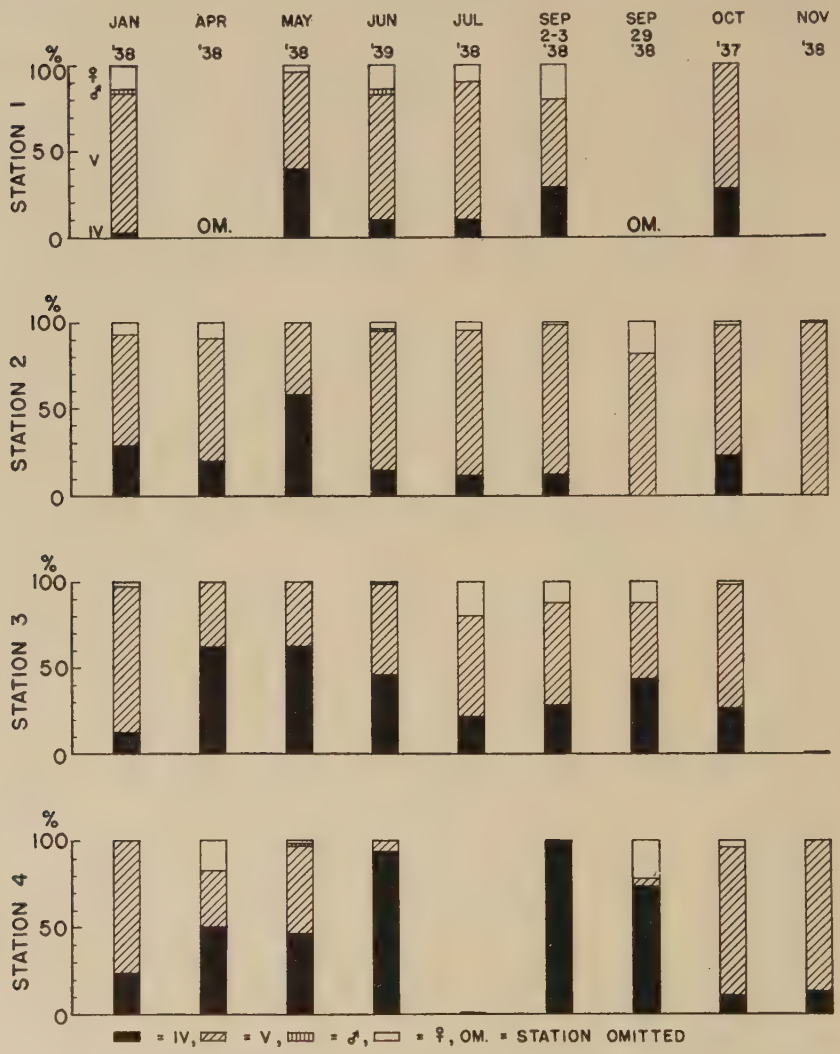

FIG. 8. *Percentage age and sex distribution of Calanus finmarchicus throughout the year* (coastal area only). On cruise of Jan. 5–9, 1939, no *Calanus* taken in this area.

gators reported that *Calanus* had two breeding periods during the year, one resulting in a short-lived spring generation,[5] and the other in a long-

[5] The conclusions of Clarke and Zinn (1937) have been erroneously stated by Bigelow and Sears as "*two* shorter-lived generations during the spring, followed by a longer one in summer."

lived generation spanning the balance of the year. They also found that the appearance of the adult males presaged the commencement of breed-

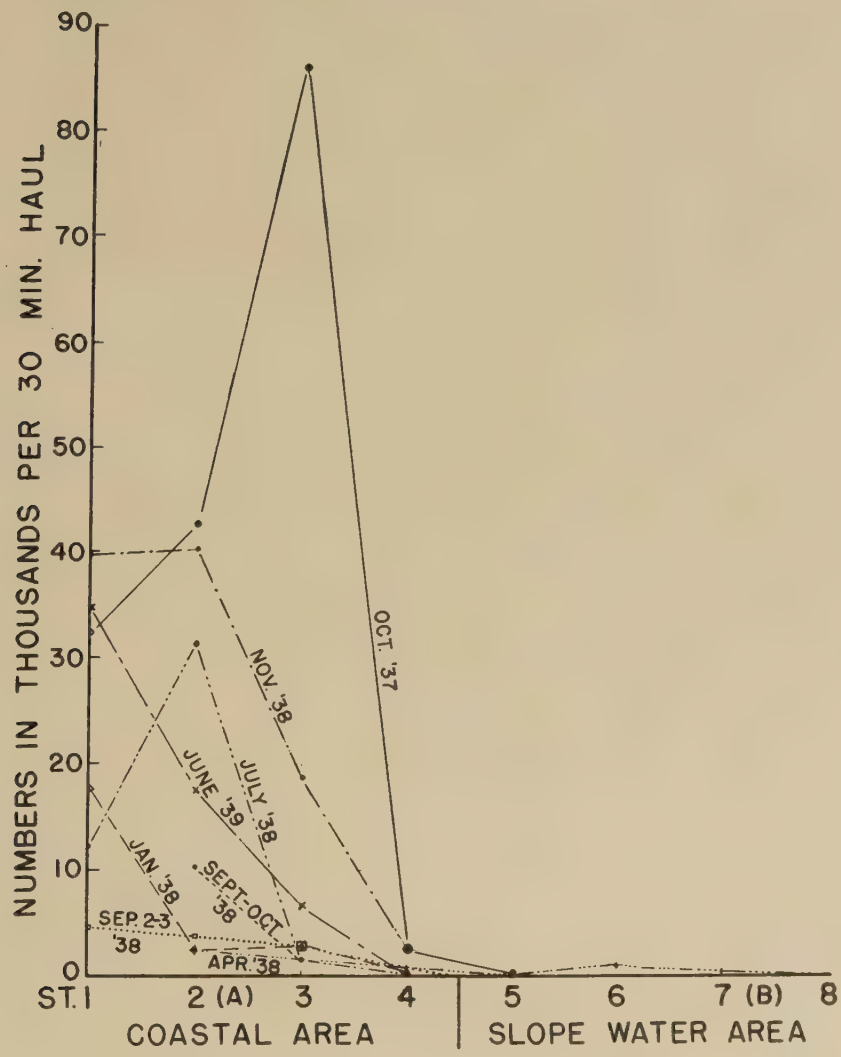

FIG. 9. *Variation in abundance of Centropages typicus (all stages) throughout the year.* Shallow haul and deep haul (weighted) at each station have been combined. On cruise of Jan. 5–9, 1939, *Centropages* taken at Station 3 only.

ing activity in this species. Consequently, the deduction seems justified that two generations of *Calanus* similarly occur each year over the whole of that part of the coastal area covered by the present investigation.

The horizontal distribution and seasonal changes in *Centropages typicus* are similarly presented in Fig. 9, in which the numbers of adult males and females and of immature specimens have been added together, and shallow and deep hauls combined. The graph shows that this species

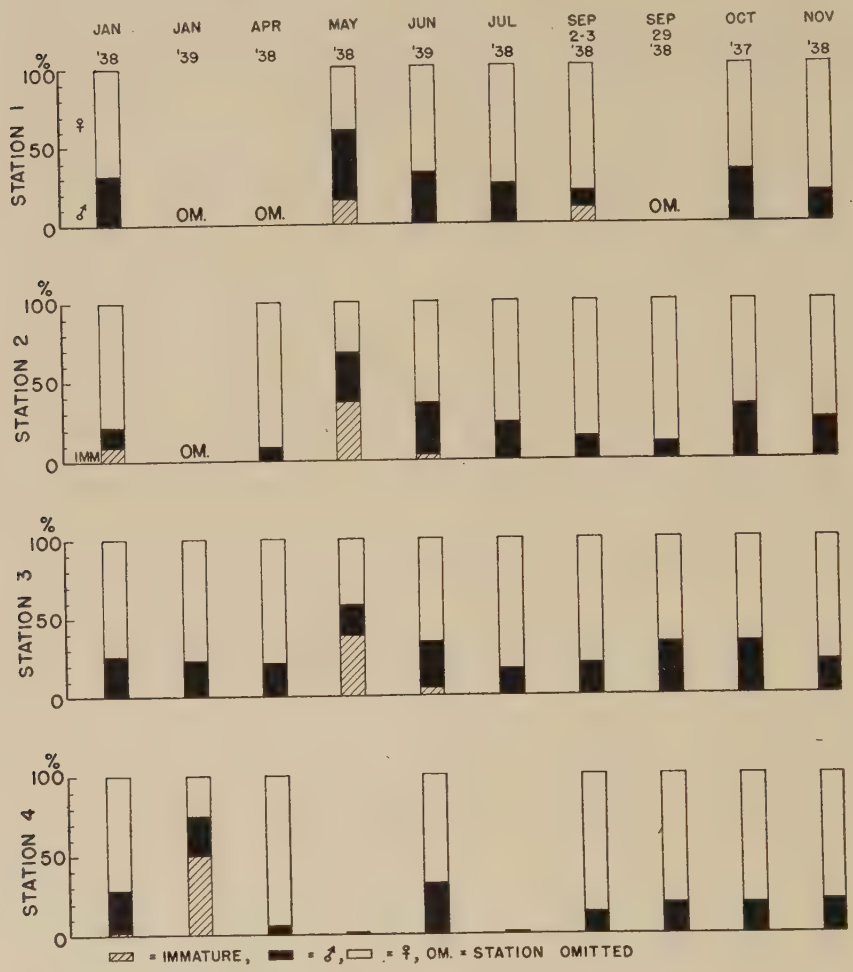

FIG. 10. *Percentage age and sex distribution of Centropages typicus throughout the year.* (Coastal area only.)

is restricted to the coastal area even more completely than was *Calanus*. Moreover, *Centropages* was never really abundant at the outer edge of this area (Station 4) and large numbers were frequently encountered near shore (Station 1). The population of this copepod was generally at a low ebb during the winter and spring months, but catches of greatly

increased size were taken from June to November. The largest hauls of the series were made early in October, 1937 but numbers were relatively small during the same period in 1938, although sizeable catches were taken in November of that year. Yet, in spite of the fact that great irregularity is encountered here as elsewhere, we may conclude that in general *Centropages* reaches its peak of abundance during the summer at a period somewhat later than that typical for *Calanus,* and that it may continue to be plentiful well into the autumn. Our data, therefore, confirm the earlier deductions of Clarke and Zinn (1937) and of Bigelow and Sears (1939).

Both male and female adults of *Centropages* were well represented in our catches in the coastal area throughout the year in contrast to the situation with *Calanus* (Fig. 10). The females were more numerous than the males in almost every case but the males most nearly reached parity in May and June and again in September and October. The immature specimens were probably not taken in their true proportions by the relatively coarse scrim net, but if abundant in the water, they were represented qualitatively in the catches. A considerable percentage of immature *Centropages* was taken by the plankton samplers with No. 2 silk mesh in May, 1938 and by the scrim nets in January, 1939. Occurrences of smaller proportions were observed in January, 1938, June, 1939 and September, 1938. Clarke and Zinn (1937) report the immature stages of this copepod to have been particularly abundant in the summer months at their station. Bigelow and Sears (1939), however, did not distinguish between the immature and the adult specimens of this species. Our information is thus too scanty to determine the time of breeding for *Centropages,* but the fact that young individuals were encountered at every season except the autumn strongly suggests that more than one breeding period and probably more than one generation occur during each year. However, since the majority of *Centropages* evidently do not pass the autumn and winter in a late copepodid stage, it appears probable that the life cycle of this species differs markedly from that of *Calanus.*

Discussion

The first impression which we derive from the foregoing data is one of variability. We have found that plankton hauls repeated within a short period at the same station or at nearby positions differed widely not only as to total quantity but also as to composition. Furthermore, from season to season the plankton oscillated with an amplitude which varied according to the location and which in certain cases was as great

as 20- to 40-fold. In addition, both the type of plankton and its abundance in any area were found to differ in the same month according to the year. It appears, then, that any plankton study in an oceanic region of this type must be prepared to deal with time and space fluctuations on both a small and a large scale. This investigation has shown that no single station will serve as an adequate index for any of the areas under present consideration—a conclusion which was suspected from plankton work elsewhere. Also, it has become clear that a network of stations repeated throughout the year for several years will be necessary before the causes underlying these fluctuations can be ascertained.

As a step in this direction, the findings of the present investigation may be compared with and added to the results of the earlier explorations in these waters which have been thoroughly analyzed by Bigelow and Sears (1939). Unfortunately almost all the quantitative plankton work in this part of the Atlantic has been confined to the waters overlying the continental shelf. The whole of the area dealt with by Bigelow and Sears corresponds to only one of the zones crossed by our cruises—namely the coastal area. Nevertheless, since this region is the most changeable and also the most important from the point of view of the commercial fisheries, a comparison is highly desirable.

The location of the "Montauk Section," as designated by Bigelow and Sears, corresponds most closely to the position of our Stations 1 to 4. The volume of the total zoöplankton taken at stations on the Montauk Section during the years 1929–32 ranged from 3 to 1,880 cc., but out of a total of about 60 hauls only five hauls were less than 100 cc. and 17 hauls were greater than 500 cc. in volume. These figures contrast rather sharply with those obtained in the present investigation. Among our 58 hauls in the coastal area only 5 were more voluminous than 500 cc. and 31 contained less than 100 cc. The volumes of hauls in the present survey were generally inferior even to those of the years 1929 and 1932 which were reported to be years of plankton scarcity. The discrepancy may be explained to some extent by the difference in the type of net employed, for the plankton measured by Bigelow and Sears was taken with a net 1 meter in diameter, the top of which was made of No. 0 silk (15 strands/cm.) and the tail of No. 2 silk (21 strands/cm.). In addition to the fact that this finer mesh silk would tend to catch more of the smaller organisms than the scrim employed by us, it may well be that the filtering efficiency of the silk is superior to that of the scrim, which was estimated by Clarke and Zinn (1937) to be as low as 20 per cent. However, the effect of the larger net and finer mesh is offset to some extent by the fact that Bigelow and Sears reduced their data to a standard haul of 20 minutes instead of the 30 minutes

employed in the present study. The combined effect of the differences in net size and in duration of haul would yield a theoretical factor of .84 to be applied to the volumes reported by the earlier workers, but the allowance which should be made for other differences in method is not known. Although the discrepancy is very likely not as great as would at first appear, nevertheless, everything considered, it seems probable that the plankton was really less abundant during the period of the present survey than it was during any of the years 1929–32.

A much more precise measure of the actual abundance of the plankton may be obtained from the hauls made with the 5-inch plankton samplers since these instruments are equipped with calibrated flow meters. Unfortunately, the samplers were not developed early enough to be used for the whole investigation, but it is of some value to examine such hauls as we have for their order of magnitude. Although the samplers are extremely useful in coastal regions, they are less satisfactory (in their present design) for work in the areas farther offshore since the scarcity of the plankton causes the catches to be inconveniently small. Even though these hauls were frequently too small to measure accurately, nevertheless, the upper limit of the richness of the population may be obtained from them. The abundance of the plankton as measured by the plankton sampler is summarized below:

	Coastal Area (Stations 1–4)	Off-shore Areas (Stations 5–9)
Total number of hauls	67	71
Number < 0.1 cc./m.^{3}	15	51
Number > 1.0 cc./m.^{3}	15	5
Average of cases 1.0–0.1 cc./m.^{3}	0.54 cc./m.^{3} (37 cases)	0.40 cc./m.^{3} (15 cases)
Maximum abundance	15.5 cc./m.^{3}	3.5 cc./m.^{3}

The foregoing data point once again to the characteristically greater richness of the coastal area as compared with the offshore areas. Beyond the edge of the continental shelf the concentration of plankton was less than 0.1 cc./m.^{3} in about 75 per cent of the cases whereas in the coastal area more than 75 per cent of the hauls indicated an abundance greater than 0.1 cc./m.^{3}. All the catches greater than 2.0 cc./m.^{3} in the coastal area and greater than 1.0 cc./m.^{3} in the offshore areas were dominated by salpae. Since in the coastal area an equal number of very large and very small hauls were taken, we may regard the majority of catches of intermediate size (1.0–0.1 cc./m.^{3}) as typical of this region. The average of the cases which fell in this category (almost all of which occurred in the warmer half of the year) is 0.54 cc./m.^{3} and may be compared with the estimate of the absolute abundance of the plankton in this area made by Bigelow and Sears and based on hauls with 1-meter

nets. These investigators reported averages of "about 0.5–0.8 cc. per cubic meter at the season of maximum production." These two estimates, reached by very different methods, agree so closely that we are led to place considerable reliance on the order of magnitude of the values obtained as an index of the actual richness of plankton in this coastal region (cf. Clarke, 1939*b*).[6] The fact that our average value is found to be at the lower limit of the range given by Bigelow and Sears adds support to the conclusion reached above that the period of the present investigation was one of relative plankton scarcity.

A further evidence that the plankton under consideration here differed significantly from that present during the period of the earlier investigation is furnished by the unusual abundance of salpae which we encountered. Bigelow and Sears reported that salpae, medusae and ctenophores ordinarily accounted for only a small percentage of the entire catch but that a maximum value of 22 per cent for the area as a whole was found in June, 1932. In our hauls, however, the total plankton for the four coastal stations combined amounted to more than twice the volume of the crustacean plankton on 6 out of the 10 cruises and on certain occasions it was several times more abundant. The inference is that during the period from October, 1937 to June, 1939 in our coastal area the plankton as a whole was relatively scarce and that the crustacea were particularly depleted, while the other elements—especially the salpae—were unusually abundant. The recurrence of such important differences in both the quantity and the complexion of the plankton in the waters over the continental shelf and their undoubted significance in the ecology of the region is further elaborated elsewhere (Sears and Clarke, 1940).

As yet we have no adequate information on the possible occurrence of annual variations in the plankton in the slope water area or in the regions farther offshore. Further quantitative investigation is demanded. Nevertheless, it is doubtful whether the plankton beyond the edge of the continental shelf ever reaches the proportions of that within the coastal area. What factor essentially underlies the differences in the richness of the standing crop in the three areas remains to be worked out. The characteristic differences in depth and the seasonal changes in temperature, which have been described above, determine what portion of the whole water column can be effectively stirred and thus bring about a regeneration of nutrients and a renewed impetus to biological production. But the details of these events are not yet adequately

[6] The agreement also adds support to the conclusion of Clarke and Bumpus (1939) and of Winsor and Clarke (1940) that a plankton net only 5 inches in diameter is as reliable as a meter net for a quantitative measure of the plankton.

known and much remains to be learned of the rates of reproduction and growth of the dominant organisms in these areas before the characteristic annual productivity of each can be ascertained. Nevertheless, the present observations make it clear that a distinct difference in the richness of the plankton of the three areas existed during the period of this investigation and since the indications are that this period was one of relative scarcity for the coastal area, we may suspect that the ratio of plankton abundance in waters over the continental shelf to that farther offshore is in general even greater than was found in the present case.

Summary

1. The abundance of the zoöplankton in the coastal water, the slope water, and the Sargasso Sea at stations between Montauk Point, N. Y., and Bermuda was investigated over a period of a year and a half by means of shallow and deep hauls made chiefly with 75 cm. scrim nets. Analysis of the plankton by volume measurement and by enumeration revealed that wide variations both in the quantity and in the composition of the hauls occurred within short periods of time and within relatively short distances.

2. A noticeable diurnal migration of the crustacean plankton was detected in the coastal water and particularly in the slope water, although the vertical distribution of the plankton as a whole was not significantly affected by diurnal movement. When all observations are combined, the surface layers do not appear to have been generally richer than the deeper strata except in the case of the Sargasso Sea station.

3. An unexpectedly great seasonal difference in the abundance of the plankton was revealed, the volume of the catches in the warm half of the year being as much as 20 times or 40 times greater than in the winter in the coastal area and as much as 10 times greater in the slope water area, but no significant seasonal change was indicated in the Sargasso region.

4. When the shallow and deep hauls throughout the year are combined, the investigation as a whole shows that the average volume of the plankton was about 4 times greater in the coastal area than in the slope water area and that the latter was about 4 times greater than at the Sargasso Sea station. Differences in the same direction but of smaller magnitude were found for the crustacean plankton.

5. Individual study of *Calanus finmarchicus* and of *Centropages typicus* showed that the abundance of these copepods, which were confined to the coastal area, fluctuated widely, the former being most numerous in spring and early summer and the latter in late summer and autumn.

6. The actual richness of the plankton in the coastal area as measured by the plankton sampler fell within the approximate range observed by earlier investigators, but all indications point to the period of the present study as one of relative scarcity. In addition, the proportion of the crustacea in the hauls was unusually low (less than half the total plankton in 6 out of 10 cruises) and the number of salpae was unusually high. The superiority in richness of the coastal area over the offshore areas probably is generally even greater than that found in the present case.

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Contribution No. 242

A STATISTICAL STUDY OF VARIATION IN THE CATCH OF PLANKTON NETS[1]

By

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INTRODUCTION

Statement of the Problem.—In a previous communication, Winsor and Walford (1936) analyzed the results of repeated vertical hauls of different types of plankton nets, making use of data available in the literature. They concluded that the observed results could be accounted for reasonably well on the assumptions that (a) the organisms were randomly distributed in the medium and (b) that the volume of medium effectively sampled varied from haul to haul. From this result it follows that as the total catch is increased (as by increasing the net size) the reliability of a population estimate is ultimately limited by variation in volume sampled; and that where such conditions hold, it is useless to attempt greater accuracy by increasing either the total catch or the fraction counted much beyond the point where 100 organisms of the kind in question are counted.

The data available in the literature did not warrant further attempts at analysis. We have felt, however, that it should be possible to go further, and to determine to some extent the factors underlying the variability. We now present the results of a study of variation in successive and simultaneous hauls under various conditions.

The general problem of the reliability of results obtained by the use of plankton nets involves a number of different questions. In the present

[1] Woods Hole Oceanographic Institution Contribution No. 242.

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paper we shall be primarily concerned with the variation attaching to the numbers caught; that is, within what limits may we expect repeated hauls in the same body of water to vary? An answer to this problem is evidently fundamental in any comparison of observations, and in answering such questions as the relative catching power of different nets.

It is evident, of course, that many other questions arise in evaluating the results of plankton hauls. For example, we have questions of the efficiency of nets, and how we are to pass from the numbers caught to the numbers present in the water. With such questions as these we are not here concerned.

We shall attempt here, then, to investigate the variability of repeated hauls in the same body of water, and the relation of this variability to size of net and manner of hauling.

Two other problems ought to be mentioned, though we shall not be concerned with them to any extent. First, there is the problem of laboratory sampling of the catch. This has been treated by others, and there seems to be no doubt that when the work is carefully done, variation from this source is comparatively small and follows well known probability laws. Second, how far in time and space is a particular catch to be taken as representative? We shall not discuss this problem, but some of our data will perhaps be found to have some bearing on it.

Material.—We have made use primarily of material of our own collection; we have also analyzed published data insofar as we have been able to use it. Our own collections consist of seven sets of hauls, made from the 40 foot power boat "Asterias" at locations within a day's run from Woods Hole. We are indebted to Mr. Dean F. Bumpus for technical assistance in the work at sea and in the subsequent enumeration of the catches. This material is more completely described below. In addition, we have made use of data published by Gardiner (1931) and Künne (1933).

Enumeration of Catch.—Each catch was diluted, mechanically stirred, and sampled as described by Clarke (1933). Those species which were present in adequate numbers were counted under the microscope. The following routine was adopted for the counting: for each species, counts were made in two samples; further samples, up to five, were counted until the total counted had exceeded 100. Occasionally, especially with the smaller nets, the entire catch of some species was counted.

Our tables give the estimated total catch for each species, and the number of samples counted in each case. The actual numbers counted can be obtained, if desired, by the use of the factors given in the tables.

The animals enumerated in our work were the following:

Calanus finmarchicus	Copepods
Metridia lucens	
Centropages typicus	
Centropages hamatus	
Pseudocalanus minutus	
Tortanus discaudatus	
Euthemisto sp. (juvenile)	Amphipod
Sagitta elegans (up to 22 mm.)	Chaetognath
Limacina retroversa	Pteropod

In several instances a species was enumerated by sex, or by development stages. We have therefore used the term group to indicate a category of animals enumerated separately.

Statistical Definitions.—We give definitions of certain statistical terms which we shall use:

The *variance* of a set of numbers is the sum of the squares of their deviations from their mean, divided by one less than their total number. That is:

$$v = \frac{S\,(x - \bar{x})^2}{n - 1}$$

The *standard deviation* of the set is the square root of the variance.

Note that we divide by $n - 1$ rather than by n.

A basic proposition in probability of which we shall make much use is the following:

Let x and y be independent random variables with mean values zero; let the mean values of their squares be σ_x^2 and σ_y^2; then the mean value of the square of their sum, σ^2_{x+y}, is

$$\sigma^2_{x+y} = \sigma_x^2 + \sigma_y^2$$

Analysis of Variance.—Given a set of data which can be divided into subsets, we can compare the variation within and between sets by means of the arithmetical procedure introduced by R. A. Fisher, known as the analysis of variance. Thus, if $x_1, x_2, \text{---} x_n; y_1, y_2, \text{---} y_n; z_1, z_2, \text{---} z_n; \text{--}$ are m sets of n observations, we can compare the variability of the means of the sets with the variability of the observations within each set. We can thus determine whether the means vary significantly more than would be expected from the within-set variability, and estimate the amount of variability which has been added to the means.

OBLIQUE HAULS

The problem with which we are here concerned is the estimation of the variability of plankton catches in a series of parallel hauls, all sampling

the same body of water. We are endeavoring to identify variations arising from different sources, and to determine the precision which attaches to a single observation made under conditions like those of our experimental series. We begin with the analysis of a series of oblique hauls, which will serve to illustrate our procedure in its simplest form. This series (Series I) consisted of twelve hauls, each of 10 minutes duration, made using two 75 cm. scrim nets (A and B) in succession according to the scheme AABBAABB—. The two nets used were of identical construction and dimensions. The original analysis was carried through keeping the nets distinct; but since no differences between them could be found (as was to be hoped), the distinction between them has been ignored in the analysis presented here.

The estimated catches are given in Table I, together with the mean and the range of variation for each group. It is apparent that the range of variation is very different for the different groups; and that this range is roughly proportional to the mean for each group. We can also observe a tendency for the numbers in any haul to be high or low together, indicating factors common to the whole haul affecting all groups in the same direction.

Under these circumstances, it is both convenient and theoretically advantageous to use the logarithm of the catches rather than the catches themselves. If we transform to logarithms we get the results found in Table II.

We now propose to assume that the factors determining the numbers in this table can be analyzed into the following:

(a) A mean for each group.

(b) A variation common to each count in a haul, differing independently from haul to haul.

(c) A residual variability, affecting each figure in the table independently.

We shall further assume that the variations under (b) and (c) are independent of each other and of the group mean, and we shall treat them as random deviations. We have thus set up a hypothetical scheme of the form,

$$y_{ij} = n_{i-} + h_{-j} + e_{ij}$$

where y_{ij} = log catch of ith group in j^{th} haul

n_{i-} = true mean of ith group

h_{-j} = haul deviation of jth haul, common to all groups

e_{ij} = individual deviations of ith group in j^{th} haul

It is now our purpose to estimate the variances (squared standard deviations) σ_H^2 and σ_{GH}^2 of the haul and individual deviations. For this purpose the computations can be very conveniently carried through in the form of Fisher's analysis of variance, giving the following table:

	Degrees of freedom	*Sum of squares*	*Mean square*
Total	47	7.4376	
Group	3	6.8298	
Hauls	11	.3500	.03182
Interaction, G × H	33	.2578	.00781

Now the mean square for interaction, .00781, is an estimate of the quantity σ_{GH}^2, the variance associated with the individual cells of the table. The mean square for hauls, .03182, is an estimate of the quantity $4\,\sigma_H^2 + \sigma_{GH}^2$, whence we get .00600 as an estimate of σ_H^2, the variance associated with the haul.

From the estimates .00781 and .00600 for the within-haul and haul to haul variances, we obtain .0884 and .0775 as the estimated standard deviations. These are obtained from the logarithms of the catches. To interpret these figures in terms of variability of the actual catches we proceed as follows:

$$.0884 = \log 1.226$$

$$.0775 = \log 1.195$$

Now a deviation of .0884 in the logarithm of the catch means that the catch has been multiplied (or divided) by 1.226. Hence we may say that one standard deviation in the logarithm corresponds to a percentage standard deviation, or coefficient of variation, of 22.6% in the catch. Similarly, a logarithmic standard deviation of .0775 corresponds to a coefficient of variation of 19.5%.

We can thus say: the complete suppression of haul to haul variation would leave variation such that each group would fluctuate about its own mean with a standard deviation of about 22.6%. The haul to haul variation itself, if all other variability could be eliminated, would be about 19.5%.

Actually, we are principally interested in knowing the uncertainty attaching to a single observation, because usually we deal with the results of single hauls. The variance of a single observation will be

$$\sigma^2 = \sigma_H^2 + \sigma_{GH}^2 = .01381$$

The standard deviation of a single observation will be the square root of this, or .117. This, we remember, is obtained from the logarithms of the catches; we have, therefore, as the percentage standard deviation, since

$$\log 1.31 = .117,$$

$$31\% = 131 - 100,$$

a value of 31%.

If we are interested in the difference between two catches, we shall usually wish to know the standard error of this difference. We shall have two cases: first, the comparison of two groups from a single haul, and

second, the comparison of catches from two different hauls. In the first case the error variance affecting the comparison is evidently $2\ \sigma_{GH}^2 = .01562$, giving a standard error for the difference of the logarithms of .125, or a percentage standard error for the ratio of 33%. For the difference of the logarithms of two catches from different hauls we have a variance of $2\ (\sigma_H^2 + \sigma_{GH}^2) = .02762$; the corresponding standard error is .166, and the percentage standard error of the ratio is 47%.

It may be well to point out that with percentage standard errors as large as those with which we are dealing, the usual concept of a standard error as giving equally probable plus and minus deviations may be misleading or even absurd. It is probably better to make any critical comparisons directly on the logarithms, and if numerical upper and lower limits, such as ± twice or three times the standard error, are desired, to find these for the logarithms, subsequently converting if necessary.

VERTICAL HAULS

(a) *Present Series.*

Our data on vertical hauls come from three sources, our own collection, and data published by Gardiner (1931) and by Künne (1933). Our data and Künne's were collected primarily for the purpose of comparing the catching power of nets, and the analysis of the results is somewhat complicated by this fact. We begin with our own data (Table III).

Here we have 8 hauls, 4 each with a ¾ meter and a 30.5 cm. net, hauled alternately. Six groups were counted, making a total of 48 observations. If now we set up the analysis of variance table, we have clearly 5 degrees of freedom from the 6 groups, and 1 from the two nets; there are then 5 degrees of freedom for net-group interaction, i. e., for differential catching power of the two nets. Considering now the haul to haul variations, we observe that the four pairs of hauls, one with each net, will give us three degrees of freedom representing differences between the totals of the pairs, and three degrees of freedom within the pairs, representing the failure of the totals for each net to agree with the overall total for each net. These two sets of three degrees of freedom may be expected to differ if there is any progressive change in population density with time; their agreement may be taken as indicating that all hauls have sampled the same population.

The remaining 30 degrees of freedom represent variations from haul to haul which affect the individual groups independently. They may be subdivided into a set of 15 between pairs of hauls, and a set of 15 within pairs, corresponding to the subdivision of the haul totals. Here again, agreement between these two sets will indicate that the composition of the population has remained constant throughout the series of hauls.

The analysis of variance corresponding to this subdivision follows:

	Degrees of freedom	*Sum of squares*	*Mean square*
Total	47	4.5392	
Group	5	2.3499	.4700
Net	1	.8560	.8560
Net × Group	5	.1002	.0200
Hauls between pairs	3	.2169	.0723
Within pairs	3	.3897	.1299
Group × Haul between pairs	15	.3887	.0259
Within pairs	15	.2378	.0158

From this table it appears that the mean squares between and within pairs do not differ significantly, either for the haul totals or for the Group × Haul interactions. We may therefore reasonably conclude that we have been sampling from an unchanging population throughout. Further, we note that the Net × Group mean square, .0200, does not differ significantly from the Group × Haul mean squares; and we therefore conclude that the groups here considered are caught in the same proportions by these two nets.

If we accept these conclusions, we may reasonably regroup the analysis of variance table as follows, putting the Net × Group together with the Group × Haul:

	Degrees of freedom	*Sum of squares*	*Mean square*
Total	47	4.5392	
Group	5	2.3499	.4700
Net	1	.8560	.8560
Haul	6	.6066	.1011
Group × Haul	35	.7267	.0208

If now we seek as before, to separate the within haul and haul to haul variances, σ_{GH}^2 and σ_H^2, we have:

$$.1011 = 6\,\sigma_H^2 + \sigma_{GH}^2$$
$$.0208 = \sigma_{GH}^2$$

whence we get

$$\sigma_H^2 = .0134,\ \sigma_H = .116$$
$$\sigma_{GH} = .144$$

As the standard deviation of the logarithm of a single observation we have $\sqrt{.0134 + .0208} = .185$, which corresponds to a percentage standard deviation of about 53%.

It may be interesting to compare these figures with those previously obtained for oblique hauls.

	Vertical	*Oblique*
σ_{GH}	.144	.0884
σ_H	.116	.0775
$\sigma = \sqrt{\sigma_H^2 + \sigma_{GH}^2}$	.185	.117
s.d. as % of mean	53%	31%

In this particular set of data the oblique hauls have been considerably more consistent than the vertical hauls. We do not assert that this will always be true; but it suggests to us that the accuracy of oblique hauls may well be worth further investigation.

A possible offset to the apparent advantage of the oblique haul is the extra time required. If we argued that two vertical hauls could be taken and counted in the time for one oblique haul, we should halve the variance of a single observation, giving a standard deviation of about .130, or a percentage standard deviation of about 35%.

We may now inquire: what is the ratio of the catches of the 75 cm. and 30.5 cm. nets used in this series, and how precisely has this ratio been determined? The mean of the differences of the logarithms of the 30.5 cm. and 75 cm. catches is $\bar{1}.086$, corresponding to an actual ratio of the catches of 0.122. The variance of the logarithm of this ratio is $2 \times .1011/24 = .00842$, giving a standard error for the logarithm of 0.092. (We use .1011, the mean square for hauls, rather than .0208, because haul to haul variation affects our ratio.) We may now argue: it is very improbable that a subsequent comparison would give a value differing from the observed $\bar{1}.086$ by more than three times the standard error; or, it is practically certain that the logarithm of the ratio will lie between $\bar{2}.810$ and $\bar{1}.362$; or, finally, the ratio itself is practically certain to lie between .065 and .230.

The ratio which would be expected from the openings of the nets is .165. This is larger than the observed .122; but the difference is not certainly established. We may remark, however, that our other material shows a similar tendency for smaller nets to catch less than would be expected from their openings.

As against this, the two nets appear to catch all the groups here discussed in the same proportion. There is no evidence that either net is relatively favorable or unfavorable to any particular group. This, it may be added, agrees with the results obtained by Künne (1933) on larger nets.

Our second series of vertical hauls consists of 30 hauls, using a 75 cm. net, a 30.5 cm. net, and a 12.7 cm. net in rotation. The data are given in Table IV. Unfortunately, only one species (*Centropages typicus*) was present in sufficient numbers in all three nets to warrant critical comparison. *Sagitta elegans* was also present in the hauls, but in numbers so small, in the two smaller nets, as to make doubtful the validity of comparisons by our previous methods. We have, however, made the computations for both species in the two larger nets.

Since the three nets were hauled independently, we have analyzed them separately, with the following results:

	Mean Squares		
	75 cm.	*30.5 cm.*	*12.7 cm.*
Haul	.3140	.1512	
G × H	.0244	.0570	.0346

Note that since we have only one species in the smallest net, the breakdown into haul and G × H is not possible.

It will be observed that the 75 cm. net shows a significantly greater mean square for haul than for G × H. For the 30.5 cm. net the difference is not statistically established, but is in the same direction. Examination of the data suggests that there is a difference between the *Sagitta* and *Centropages* figures. If we compute the mean squares by species, we get the following:

	75 cm.	*30.5 cm.*	*12.7 cm.*
Centropages	.1705	.0328	.0346
Sagitta	.1680	.1754	

Here in the 30.5 cm. net the mean square for *Sagitta* is significantly greater than that for *Centropages*. To judge by the catch figures, there was apparently a change in the population, the early hauls catching more *Sagitta* than the later.

The ratio of catches of the three nets, taking the 75 cm. net as 1, is:

	75 cm.	*30.5 cm.*	*12.7 cm.*
Centropages	1	.165	.0315
Sagitta	1	.132	
Both species	1	.148	

It remains to be inquired whether the 12.7 cm. net has caught *Sagitta* in the proportions which would be indicated by the catch ratio for *Centropages*. We may reach an estimate of the total catch of *Sagitta* to be expected in the 12.7 cm. net in the ten hauls as follows:

In the first haul 241 *Centropages* were taken; with the 75 cm. net, 14,750 *Centropages* and 123 *Sagitta* were taken; hence, we would expect $\frac{241 \times 123}{14750}$ = 2.0 *Sagitta*. Proceeding for the succeeding hauls, we get an estimated catch in all ten hauls of 20.9 *Sagittae*, against an observed total of 9. Testing this by χ^2 with one degree of freedom, we find a probability of somewhat less than .001 that such a difference could have arisen by chance. It appears highly probable, then, that in this series the smallest net has been less efficient in catching *Sagittae* than in catching *Centropages*. The data, however, are not sufficiently extensive to allow us to go farther than this.

(b) *Gardiner's Data*

Gardiner (1931) has published data on vertical hauls made with the international net. We have used here his second series. Gardiner lists

three groups of animals and the total catch. We have used his three groups (*Calanus*, *Temora*, and *Pseudo-* and *Paracalanus*) and a fourth (all others) obtained by subtraction.

Inspection of his data suggests that during the hauls (which extended over some eleven hours) there have been progressive changes in the population, which it would be desirable to eliminate. We have therefore paired the hauls (so far as this was possible), pairing hauls taken within 10 minutes, and determined the variation both within and between pairs. The analysis of variance table runs:

	Degrees of freedom	*Sum of squares*	*Mean square*
Total	143	13.7486	
Groups	3	6.8551	
Hauls	35	5.0202	
Between Pairs	20	4.7113	.2356[a]
Within Pairs	15	.3089	.0206[b]
Groups × Hauls	105	1.8733	
G × between	60	1.2933	.0216[c]
G × within	45	.5800	.0129

[a] Significant at 1% level.
[b] .0206/.0129 = 1.59; F(5%) = 1.89, d.f. 15 and 45.
[c] .0216/.0129 = 1.67; F(5%) = 1.59, d.f. 60 and 45.

From this table it is clear (a) that there is significant variation in the totals from one pair of hauls to another; but (b and c) it is not certainly established either that there is variation in the haul totals within pairs, or that there is variation in the composition of the population from pair to pair. We may, however, reasonably observe that the changes to be expected in the population are gradual, and we may ask whether grouping hauls taken within an hour would lead to different conclusions. We have then:

	D.F.	*Sum of squares*	*Mean square*
Total	143	13.7486	
Groups	3	6.8551	
Hauls	35	5.0202	
Between hours	7	3.6346	.5192[a]
Within hours	28	1.3856	.0495[b]
Groups × Hauls	105	1.8733	
G × between	21	.5922	.0282[c]
G × within	84	1.2811	.0152

[a] Significant at 1% level against .0495.
[b] Significant at 1% level against .0152.
[c] .0282/.0152 = 1.85; F(5%) = 1.69; F(1%) = 2.07.

Comparing this table with the preceding, we see that variation of haul totals within hours is significant; and that the variation of group proportions from hour to hour is probably significant.

If now we attempt to carry through our preceding analysis to determine the variances associated with the different categories, we have the difficulty that the number of hauls is not the same for each hour. We can, however, get the following estimates:

σ_H^2 :	.0265	haul to haul variance totals between hrs.
σ_{HW}^2 :	.0086	haul to haul variance totals within hrs.
σ_{GH}^2 :	.0030	variance between hrs. species to species.
σ_{GHW}^2:	.0152	species to species variance within hrs.

These estimates may now be used to give us the reliability of a single observation. If our observation is to be regarded as representative of the hour during which it was made, its variance will be $\sigma_{HW}^2 + \sigma_{GHW}^2$, or .0238. From this we get a standard deviation of .154, or a percentage standard deviation of 43%. If we desired to take the haul as representative of a longer period, as of the whole twelve hours, we would have a variance of .0533, or a standard deviation of .231, giving a percentage standard deviation of 70%.

Künne's Data

Künne's data afford the most extensive series of net comparisons with which we are acquainted. Unfortunately for our present purposes, not many of these hauls contain large catches of several species. We have chosen for analysis his series 62–65 and 73–76, all from his Table 8, in which the Helgoland larva net is compared with the Hensen egg net. In these hauls, a complete series consisted of two hauls of the Helgoland larva net, preceded and followed by a haul of the Hensen net. The analysis of variance runs:

	Series 62–65			*Series 73–76*		
	D.F.	*S. Sq.*	*Mean Sq.*	*D.F.*	*S. Sq.*	*Mean Sq.*
Total	79	43.4623		63	10.4320	
Groups	4	33.6675	8.4169	3	3.0573	1.0191
Net	1	7.7626	7.7626	1	5.8504	5.8504
N × G	4	.0458	.0114	3	.0027	.0009
Haul totals						
Between pairs	7	.2766	.0395	7	.0432	.0062
Within pairs	7	.2943	.0420	7	.1976	.0282
G × Between	28	.6127	.0219	21	1.0356	.0493
G × Within	28	.8028	.0287	21	.2452	.0117
	70	1.9864		56	1.5216	

We may now remark that there is no significant difference between the mean square of haul totals for between and within pairs; nor, in the case of series 62–65, is there any difference in the interaction G × Between and G × Within. In series 73–76 there is a significantly greater mean square (.0493 vs. .0117) for G × Between than for G × Within, indicating significant changes in the percentage composition of the population during the series of hauls. On the whole, however, it seems reasonable to combine the G × Between and G × Within interactions. Further, there seems to be no indication of any essential difference between the two sets of data as regards haul mean square or G × Haul interaction. We may therefore reasonably compute a mean square for error by combining the last four lines from both tables, giving:

D.F.	*S. Sq.*	*Mean Sq.*	*S.D. of log.*	*S.D., % mean*
126	3.5080	.0278	.167	47%

This is a somewhat greater variability than Winsor and Walford found for Künne's data as a whole. They indicated that a coefficient of variation of around 25% seemed to give a good fit to Künne's data. The discrepancy does not seem serious to us, for several reasons. First, we are dealing here with only a small portion of Künne's data. Second, Winsor and Walford were dealing entirely with discrepancy between pairs of catches; as we have said, there is evidence in the analysis above of variation in the composition of the population during the entire series of hauls. We should therefore expect our computations to show a greater variation.

We may conveniently summarize our work on the precision of vertical hauls with a comparison of standard deviations, expressed as the standard deviation of the logarithm of a single observation, and also as a percentage of the mean.

	σ of log.	*σ, % of mean*
Our data	.185	53%
Gardiner's data	.154	43%
Künne's data	.167	47%

The agreement between these standard deviations seems to us very satisfactory. We conclude that in vertical hauls made with good technique we may expect that the standard deviation of a single observation will be from 45 to 50% of the mean.

HORIZONTAL HAULS

(a) *Statistical Analysis.*

We are not aware of any published study of the variability of horizontal hauls. We have data on four series of such hauls, two of which are extensive enough to warrant detailed analysis. The data are given in Tables VII,

VIII, IX and X. In the first two of these series three nets, a 75 cm. net and two 12.7 cm. nets were towed simultaneously. The large net was placed at 30 meters, and the small nets at one meter above and below. The bridles were adjusted to bring the mouths of the nets in the same vertical plane. The two small nets were alternated in the top and bottom position in successive hauls. In the third series, the two 12.7 cm. nets were towed simultaneously at 29 and 30 meters, without the large net.

We originally carried through the analysis keeping the two small nets separate. As was to be hoped, there was no evidence of difference between them; and they have therefore not been distinguished in the analysis presented here. As against this, however, marked differences exist between upper and lower nets, corresponding to considerable (apparent) vertical gradients in plankton density. These differences will be discussed at greater length below.

The analysis of variance for these hauls runs as follows:

Series V

	Sum of squares	*Degrees of freedom*	*Mean square*
Total	54.5735	149	
Group	36.1323	4	
Hauls	3.9880	9	.4431
$G \times H$	6.4360	36	.1788
Nets	5.6839	1	
$N \times G$	.3147	4	.0787
$N \times H$	.2708	9	.0301
$N \times G \times H$	.2495	36	.0069
Position	.3709	1	.3709
$P \times G$	.1572	4	.0393
$P \times H$	.6528	9	.0725
$P \times G \times H$	.3354	36	.0093

Series VI

	Sum of squares	*Degrees of freedom*	*Mean square*
Total	47.8319	143	
Group	29.2877	5	
Hauls	2.4040	7	.3434
$G \times H$	7.5384	35	.2154
Nets	3.7151	1	
$N \times G$	.1855	5	.0371
$N \times H$	.6606	7	.0944
$N \times G \times H$	.4508	35	.0128
Position	.1692	1	.1692
$P \times G$	2.0390	5	.4078
$P \times H$	.4981	7	.0712
$P \times G \times H$	.8835	35	.0252

Inspection of these figures shows that the corresponding mean squares in the two tables are of generally the same order of magnitude; the conspicuous exceptions are the mean squares for Position and Position × Group, which we shall discuss later. Aside from these, the two sets of figures are sufficiently nearly alike to indicate that essentially the same sources of variation have acted in both cases. We therefore have proceeded to combine the two sets to get estimates of these sources of variation.

We begin with the triple interactions, $N \times G \times H$ and $P \times G \times H$. Since in each series the triple interactions are essentially alike, it seems reasonable to suppose that they represent essentially the same residual variance. The two series, however, are based on different numbers of degrees of freedom; we therefore add the sums of squares and the degrees of freedom to reach a weighted final estimate of the residual variance, σ_{NGH}^2:

.2495	36	
.3354	36	
.4508	35	
.8835	35	
1.9192	142	$\sigma_{NGH}^2 = .01351$

We now consider the two factor interactions $N \times H$ and $P \times H$. These are of about the same order of magnitude. It seems reasonable to suppose that they reflect essentially variations due to the failure of nets attached to the same wire to fish exactly alike in successive hauls. Such variations might arise, for example, if the nets were not hung on the wire in exactly the same manner in each haul. If we call the component of variance arising from this source σ_{NH}^2, we have to observe that the mean squares for $N \times H$ and $P \times H$ in Series V are estimates of $5\,\sigma_{NH}^2 + \sigma_{NGH}^2$, while those in Series VI are estimates of $6\,\sigma_{NH}^2 + \sigma_{NGH}^2$; and that the degrees of freedom differ in the two cases. Proceeding as before, we add the sums of squares and degrees of freedom:

		Sum of squares	*D.F.*	*Quantity estimated by S. Sq.*
Series V	$N \times H$	.2708	9	$45\,\sigma_{NH}^2 + 9\,\sigma_{NGH}^2$
	$P \times H$	.6528	9	$45\,\sigma_{NH}^2 + 9\,\sigma_{NGH}^2$
Series VI	$N \times H$	.6606	7	$42\,\sigma_{NH}^2 + 7\,\sigma_{NGH}^2$
	$P \times H$	.4981	7	$42\,\sigma_{NH}^2 + 7\,\sigma_{NGH}^2$
		2.0823	32	$174\,\sigma_{NH}^2 + 32\,\sigma_{NGH}^2$

Deducting $32\,\sigma_{NGH}^2 = .4323$, derived from our previous estimate of σ_{NGH}^2, and dividing by 174, we get as an estimate of σ_{NH}^2, .0095.

We consider next the $N \times G$ interaction. This measures the extent to which the proportions of the different groups vary with net size—i. e., the amount of differential selection by nets of different sizes. This interaction

is statistically significant, that is, it represents more than mere random variation of the kind represented by the triple interactions; but its physical significance is not so clear. It may actually represent differential selection with net size; but it could also arise out of differential density gradients between groups. In either case we have to face the uncertainty introduced by this factor. If we regard the particular groups here counted as simply a random sample of the kind of organisms for which these nets are suitable, then a portion of our uncertainty in the interpretation of any count is attributable to what we must regard as random variation in differential catching power. Likewise, any part of the $N \times G$ interaction which really arises out of density gradients would seem appropriately to be regarded as part of the random disturbing elements.

As against this, if we proposed to confine our further investigations to the particular groups here studied, it would be appropriate to determine net ratios for each group separately, and use these ratios in our comparisons. This, however, is not the purpose of our present investigation.

Proceeding as in the case of the $N \times H$ interaction, we have:

	S. Sq.	*D.F.*	*Quantity Estimated*
324 $N \times G$	.3147	4	$40\,\sigma_{NG}^2 + 4\,\sigma_{NGH}^2$
327 $N \times G$	.1855	5	$40\,\sigma_{NG}^2 + 5\,\sigma_{NGH}^2$
	.5002	9	$80\,\sigma_{NG}^2 + 9\,\sigma_{NGH}^2$
$9\,\sigma^2 =$	.1216		
	.3786	$= 80\,\sigma_{NG}^2$	
$\sigma_{NG}^2 = .0047$			

We may now consider the position effect and the $P \times G$ interaction. As has been said, we have compared the catch of the upper against the lower net. The mean square for position is a measure of the consistency with which the difference between these two is maintained over all groups. The $P \times G$ interaction measures the variation of this difference from group to group. It is apparent that in hauls 324, the density gradient was in the same direction for all groups; in hauls 327, there were differences in direction of the gradient. The actual values of the ratio upper to lower net for the two series were:

	Series V	*Series VI*
Calanus V	1.26	1.52
Calanus ♀	1.21	1.54
Metridia	1.27	0.28
Centropages	1.11	1.17
Euthemisto	1.83	1.67
Sagitta	—	1.93

The interpretation to be put on these figures is not entirely clear to us. Their statistical significance is well enough established, that is, we cannot reasonably suppose them to have arisen through random sampling errors. We hesitate, however, to assert that they give a true picture of the distribution in depth of plankton organisms. Were this the case, we should have to reckon with vertical distributions of population in which the density might change by two to three fold in a two meter range in depth. Such a variation is physically possible; but that the stratification should be so sharp and maintained so uniformly over a period of several hours, does seem to us so surprising that other possible explanations ought to be sought and examined.

One possible explanation (as to which, unfortunately, we have no evidence one way or the other) might lie in the reactions ("flight reactions") of the organisms to disturbance. If organisms characteristically reacted by an upward or downward movement to a disturbance, the result would be an apparent density gradient upward or downward. Such an explanation cannot be tested with our present knowledge. We hope to investigate this question in the future.

If now we ask: what information have we as to the effect of this density gradient effect, to whatever cause we attribute it, on the accuracy of our estimate of a particular group, we may reason as follows. If we propose to generalize from the particular groups caught in the present hauls, we are in effect assuming that there is a random component of density gradient whose magnitude we have to estimate from our data on Position and $P \times G$. We have, then, no reason for wishing to evaluate a variance for position as such, but rather we assume that there is a variance σ_{PG}^2 which enters into both the observed position and $P \times G$ mean squares. But we further observe that the position mean square differs from the $P \times G$ mean square by containing a part due to the $P \times H$ interaction. Actually the mean squares for position and for $P \times G$ are estimates of:

$$\text{Position: } n_H\sigma_{PG}^2 + n_G\sigma_{PH}^2 + \sigma_{PGH}^2$$

$$P \times G \quad n_H\sigma_{PG}^2 \qquad\qquad + \sigma_{PGH}^2$$

where n_H and n_G are the number of hauls and groups. Further, our two sets of hauls are based on different numbers of degrees of freedom. If we add the sums of squares for position and $P \times G$ from the two sets of data, we obtain:

	S. Sq.		Quantity Estimated
P	.3709		$10\,\sigma_{PG}^2 + 5\,\sigma_{PH}^2 + \sigma_{PGH}^2$
$P \times G$	.1572		$40\,\sigma_{PG}^2 + 4\,\sigma_{PGH}^2$
P	.1692		$8\,\sigma_{PG}^2 + 6\,\sigma_{PH}^2 + \sigma_{PGH}^2$
$P \times G$	2.0390		$40\,\sigma_{PG}^2 + 5\,\sigma_{PGH}^2$
Total	2.7363		$98\,\sigma_{PG}^2 + 11\,\sigma_{PH}^2 + 11\,\sigma_{PGH}^2$
	.2530	=	$11\,\sigma_{PH}^2 + 11\,\sigma_{PGH}^2$
	2.4833	=	$98\,\sigma_{PG}^2$
	.0254	=	σ_{PG}^2

(Note: σ_{PH}^2 and σ_{PGH}^2 have previously been estimated as .0095 and .0135 respectively.)

We next consider the question of the $G \times H$ interaction. This arises from the failure of all groups to be represented in the same proportions in the totals of each haul. To estimate the variance σ_{GH}^2 attributable to this variation we proceed as previously:

$$\begin{aligned} 6.4360 &= 108\,\sigma_{GH}^2 + 36\,\sigma_{NGH}^2 \\ 7.5384 &= 105\,\sigma_{GH}^2 + 35\,\sigma_{NGH}^2 \\ \hline 13.9744 &= 213\,\sigma_{GH}^2 + 71\,\sigma_{NGH}^2 \end{aligned}$$

whence we get

$$.0611 = \sigma_{GH}^2$$

Finally we have to consider the question of variation of the haul totals. It is not certain from the analysis of variance tables that there is a significant variation of the haul totals; but there seems to be reason to suppose that such a component of variation ought to exist (since it is hardly reasonable to suppose that speed, duration of haul, etc., are really devoid of variation from haul to haul). Further, in both series the mean square for hauls is actually greater than the $G \times H$ mean square. Proceeding, then, to determine the variance σ_H^2, we have:

$$\begin{aligned} 3.9880 &= 135\,\sigma_H^2 + 27\,\sigma_{GH}^2 + 45\,\sigma_{NH}^2 + 9\,\sigma_{NGH}^2 \\ 2.4040 &= 126\,\sigma_H^2 + 21\,\sigma_{GH}^2 + 42\,\sigma_{NH}^2 + 7\,\sigma_{NGH}^2 \\ \hline 6.3920 &= 261\,\sigma_H^2 + 48\,\sigma_{GH}^2 + 87\,\sigma_{NH}^2 + 16\,\sigma_{NGH}^2 \end{aligned}$$

Using the previous estimates of σ_{GH}^2, etc., we get .0093 as an estimate of σ_H^2.

We may summarize these results as follows:

$$\begin{aligned} \sigma_{NGH}^2 &= .0135 \\ \sigma_{NH}^2 &= .0095 \\ \sigma_{NG}^2 &= .0047 \\ \sigma_{PG}^2 &= .0254 \\ \sigma_{GH}^2 &= .0611 \\ \sigma_H^2 &= .0093 \end{aligned}$$

As before, we may ask: what is the standard deviation of a single observation made under conditions similar to those of the present investigation? That is, suppose we hauled a single net once, and enumerated a particular group; what estimate can we make of the precision of such a figure? If we simply add the variances just found, we get as the variance of a single observation .1235; the corresponding standard deviation is .351, giving a percentage standard deviation of 124%. It is probably more instructive to consider how the actual catch varies. Let us suppose that the actual catch is 1000 organisms; then the logarithm of the catch will be 3.000. For various multiples of the standard deviation in excess or defect of this we have the following:

Deviations	*log catch*	*actual catch*
-2σ	2.298	199
$-\sigma$	2.649	446
σ	3.000	1000
$+\sigma$	3.351	2240
$+2\sigma$	3.702	5040

This variability is evidently large. It may, however, reasonably be urged that the present series of hauls have extended over a considerable period of time—four of five hours—and it is quite possible that changes in the population may have occurred. This idea is supported by the large size of σ_{GH}^2, which reflects variations in the proportions of species in the different hauls. One may, then, desire to consider a shorter period of time than that covered by the whole of these hauls, say the time from one haul to another. In this case we shall group the hauls by pairs, and consider the variability within and between pairs. Carrying through the computation, we get as an estimate of σ_{GH}^2 within pairs .0199. Using this in place of the previous .0611, we get for the standard deviation of the logarithm of a single observation .286, or a percentage standard deviation of about 93%. Our previous table now becomes:

Deviations	*log catch*	*actual catch*
-2σ	2.428	268
$-\sigma$	2.714	518
σ	3.000	1000
$+\sigma$	3.286	1930
$+2\sigma$	3.572	3730

As a check on these computations, it is of some interest to examine the results obtained if we consider only the figures given by the large net. In this case we are able to use ten hauls in each series. The analysis of variance runs:

HAULS 324

	D.F.	S. Sq.	Mean Sq.	Estimate of
Total	49	8.1135		
G	4	4.6144	1.1536	
H	9	1.3411	.1490	$5\,\sigma_H^2 + \sigma_{GH}^2$
$G \times H$	36	2.1580	.0599	σ_{GH}^2

HAULS 327

Total	59	15.0179		
G	5	8.9180	1.7836	
H	9	1.7330	.1926	$6\,\sigma_H^2 + \sigma_{GH}^2$
$G \times H$	45	4.3669	.0970	σ_{GH}^2

The two estimates of σ_{GH}^2 do not differ significantly. We may therefore resonably combine the two sets of data to get an estimate of σ_H^2.

$$
\begin{array}{rl}
1.3411 \text{ est. of } & 45\,\sigma_H^2 + 9\,\sigma_{GH}^2 \\
1.7330 \text{ est. of } & 54\,\sigma_H^2 + 9\,\sigma_{GH}^2 \\
\hline
3.0741 \text{ est. of } & 99\,\sigma_H^2 + 18\,\sigma_{GH}^2 \\
2.1580 \text{ est. of } & 36\,\sigma_{GH}^2 \\
4.3669 \text{ est. of } & 45\,\sigma_{GH}^2 \\
\hline
6.5249 \text{ est. of } & 81\,\sigma_{GH}^2 \\
1.4500 \text{ est. of } & 18\,\sigma_{GH}^2 \\
.0806 \text{ est. of } & \sigma_{GH}^2
\end{array}
$$

Whence we have 1.6241 as an estimate of $90\,\sigma_H^2$, and .0164 as our estimate of σ_H^2. As the variance of a single observation we shall then have $.0164 + .0806 = .0970$. This is lower than the .1235 we obtained previously; but we may observe that the previous estimate includes the (apparent) vertical density gradients as a component of error. We have previously suggested the possibility that these gradients are of a different nature from the usual error components. If we deduct from .1235 the component .0254 for σ_{PG}^2, we are left with .0981, which is very close to the figure .0970 for the large net alone. We do not lay particular stress on this agreement; it suggests, however, that the data as a whole are reasonably homogeneous.

(b) *Catching power of different sizes of nets.*

The determination of the relative catching power of the two nets is of interest, and it is also a matter of importance to know the precision of this determination. We may reason as follows:

In any particular haul, we have determinations of the catch on a number of groups. Letting M, L, U be the logarithms of the catch of the middle, lower and upper nets, the logarithm of the ratio is $\frac{1}{2}(2M - L - U)$. If

we have say, 10 hauls with five groups in each, we have a total of 50 determinations of the ratio. Our best estimate will be given by the mean of these 50.

Now to what errors is this estimate subject? We have suggested that the following sources of error should be considered as affecting our data:

$$\left.\begin{matrix}\sigma_H^2\\ \sigma_{GH}^2\\ \sigma_{PG}^2\end{matrix}\right\} \qquad \left.\begin{matrix}\sigma_{HN}^2\\ \sigma_{NG}^2\\ \sigma_{NGH}^2\end{matrix}\right\}$$

The first group does not affect the precision of our net ratio; the second group does. But we have also to observe that the second group contains three sources of error which act differently. σ_{HN}^2 represents error affecting all hauls on a particular species. σ_{NHG}^2 represents error varying independently from observation to observation.

Consider any single determination,

$$r = \tfrac{1}{2}(2M - L - U)$$

Let σ^2 be the variance of M, L, U. Then we have

$$\sigma_r^2 = \frac{6\,\sigma^2}{4}$$

But actually our r is the mean of 50 single values:

$$\bar{r} = \frac{1}{50}\,Sr;$$

and the errors in these 50 values are not independent. We have, actually, 10 hauls and 5 species. Instead, then, of having

$$\sigma_{\bar{r}}^2 = \frac{1}{50}\,\sigma_r^2 = \frac{1}{50}\cdot\frac{3}{2}\,\sigma^2$$

we shall have:

$$\sigma_{\bar{r}}^2 = \frac{1}{50}\cdot\frac{3}{2}\,(\sigma_{NGH}^2 + 10\,\sigma_{NG}^2 + 5\,\sigma_{NH}^2)$$

In our second series, we have 6 groups and 8 hauls; we get then

$$\sigma_{\bar{r}}^2 = \frac{1}{48}\cdot\frac{3}{2}\,(\sigma_{NGH}^2 + 8\,\sigma_{NG}^2 + 6\,\sigma_{NH}^2)$$

Substituting our estimates of the σ^2, we get

$$\sigma_{\bar{r}}^2 = \frac{1}{50}\cdot\frac{3}{2}\,(.1081) \text{ and } \sigma_{\bar{r}}^2 = \frac{1}{48}\cdot\frac{3}{2}\,(.1080)$$

As the variance of our combined estimate we shall have very closely

$$\sigma_{\bar{r}}^2 = \frac{.3243}{196} = .001655$$

giving $\sigma_{\bar{r}} = .0407$ as the standard error of the logarithm of the ratio of the 12.7 cm. net to the 75 cm. net.

The logarithm of the ratio in series 324 was 1.7122, and in series 327 was 1.6414. The (weighted) mean of these is 1.6775, and the standard deviation of this determination is .0407. Expressed as the ratio of catches of 12.7 cm./75 cm., we have a value .0210, and taking twice the standard error, we have limits .0174 and .0253 as lower and upper bounds within which the ratio is nearly certain to lie. The ratio calculated from the openings is .0285, which is well outside our limits. We may summarize by saying that the small nets apparently catch about 25% less than would be expected from the area of their openings relative to the 75 cm. net.

The question of differential selection by the nets deserves further consideration. We have previously indicated that the statistical significance of the net × group interaction is sufficiently established, but we also pointed out that its interpretation was not completely clear. We may tabulate the net ratios by groups for the two series separately.

	Series V	*Series VI*
Calanus V	.0152	.0211
Calanus ♀	.0163	.0243
Centropages	.0214	.0256
Metridia	.0193	.0283
Euthemisto	.0286	.0232
Sagitta	—	.0163
All groups	.0198	.0228

If there were any important differential selection by the nets, we should expect that the same groups would show high or low ratios in both series. No such consistency is apparent, and we therefore incline to the belief that the differences in net ratio for different species do not reflect true differences in the nets, but rather random effects which are properly to be included in observational error.

Since the variation of the smallest net is no greater than that of the nets with which it was compared and since there is no indication that the small net fails to catch large and small, active and inactive animals in the same proportion as the large net, we may conclude that under the present conditions of work a net as small as 12.7 cm. in diameter is as reliable for the groups of plankton considered as a net of the more usual size (75 cm. in diameter). Small nets are cheaper, are more easily handled in rough weather, can be more readily rigged for closing, and may be furnished with a

volume meter. A device for the quantitative investigation of zooplankton which incorporates these advantages has recently been developed in the form of the "plankton sampler"—a 5-inch (12.7 cm.) tube and net equipped with shutter and meter (Clarke and Bumpus, 1939).

In addition to the two series of horizontal hauls just discussed, we have a short series (VII) of horizontal hauls made with the two small nets. The data are presented in Table IX. Here inspection shows that there is no such clear evidence of density gradients as in the preceding series. If we carry through the analysis of variance on the logarithms, omitting Sagitta, because the numbers are small, we obtain:

	D.F.	*S. Sq.*	*Mean square*
Total	49	12.6197	
Groups	4	7.8496	
Hauls	4	.2611	.0653
$G \times H$	16	3.8027	.2377
Position	1	.0188	.0188
$P \times G$	4	.0569	.0142
$P \times H$	4	.2777	.0694
$P \times G \times H$	16	.3528	.0220

It is clear that there is no evidence here of any density gradients. This fact suggests that the presence of the 75 cm. net was responsible in some way for the gradient observed in the other series. The mean square for $P \times G \times H$ agrees well with the figure previously obtained of .0135. The $G \times H$ mean square is large; this would be expected from examination of Table IX, since this table shows considerable changes with time in the catch of several of the groups. A breakdown into between and within pairs of hauls, pairing the first two and last two hauls, gives a mean square for $G \times H$ within hauls of .0317, which is not far from the figure previously found. It appears, therefore, that except as regards density gradients, the present series agrees well with those previously treated.

The absence of any significant density gradients in this series suggests, of course, that the gradients previously found are in the nature of artifacts. This is the more true because this series was made immediately following our Series VI. We can only repeat our previous suggestion that the gradients may be due to reaction of the organisms to disturbance by the nets, with the added suggestion that if this is the cause, the disturbance is apparently much greater when the larger net is used.

We have also a series of ten horizontal hauls made with a single 75 cm. net, the data for which are presented in Table X. It will be observed that *Centropages typicus*, ♂, *and C. hamatus* ♀ were not enumerated in the first haul. We have allowed for this in our computations, using the iterative

procedure suggested by Snedecor (2nd Ed., 1938, § 11.5). Inspection of the data shows that we are dealing here with a peculiar situation, in that the even numbered hauls are with very few exceptions higher than the corresponding odd numbered hauls. Unfortunately there is nothing in the records to indicate the source of variation; it might, for example, have arisen if windward and leeward hauls had been alternated.

The analysis of variance table for this data follows:

	Degrees of freedom	*Sum of squares*	*Mean square*
Total	57	14.7133	
Groups	5	11.1253	
Haul:			
Between pairs	4	.7292	.1823
Odd-even	1	1.6335	1.6335
Within pairs	4	.2185	.0546
$G \times H$:			
Between pairs	20	.3105	.0155
Odd-even	5	.1419	.0284
Within pairs	18	.5544	.0308
All $G \times H$	43	1.0068	.0234

It is clear that the largest source of variability is the difference between odd and even hauls. We observe, however, that there is no indication that these differences have affected the percentage composition of the hauls, since the $G \times H$ mean squares do not show significant differences. We may therefore take the figure .0234 as an estimate of σ_{GH}^2. This figure may be compared with our previous analysis. We had then $\sigma_{GH}^2 = .0611$, $\sigma_{NGH}^2 = .0135$, whence we get .0746 as the variance comparable with our present .0234. More appropriately, perhaps, we may use the figure for σ_{GH}^2 within pairs, which was .0199, so that we have $.0199 + .0135 = 0.334$ against .0234 in the present series. We consider the agreement good.

We do not feel that an attempt to estimate σ_H^2 is warranted, in view of the peculiar characteristics of the data. It appears, however, that after allowance has been made for the difference between odd and even hauls, the order of magnitude of the haul mean square is about what would be expected.

SUMMARY AND CONCLUSIONS

1. The variation in seven series of oblique, vertical and horizontal plankton hauls, with nets of the same and of different sizes, has been studied statistically. In addition, vertical hauls from two other sources (Gardiner, 1931, and Künne, 1933) have been analyzed and compared with our own data.

2. The percentage variability was essentially the same for all the groups of animals considered. We may therefore conclude that any local irregulari-

ties in distribution (e. g., local swarming) were essentially alike for all groups.

3. One series of oblique hauls is presented, and in this series, the standard deviation of a single observation was about 31%. Eliminating haul to haul variation, there was a residual standard deviation of about 23%; the standard deviation of the haul to haul variation alone was about 20%.

4. Two series of vertical hauls of our own collection are presented. In one, the standard deviation of a single observation was about 53%. In the second, the data are insufficient to warrant a complete analysis; there is some indication of a greater haul to haul variability than in the preceding series. Gardiner's and Künne's series give standard deviations for a single observation of 43% and 47% respectively.

5. Four series of horizontal hauls are presented, two of which have been analyzed at length. The third, which is less extensive, confirms (with one exception, noted below) the indications of the other two. In these hauls, the standard deviation of a single observation is about 124%, if we wish to regard the observation as representative of conditions during a period comparable with the duration of our series (say four to five hours). A considerable part of this variation arises out of changes in the proportions of the population with time; if we eliminate these, and regard our single observation as representative of conditions during an interval comparable with that from one haul to the next (say about a half hour) the corresponding standard deviation is about 93%.

6. In the first two horizontal series, marked vertical gradients in population density occurred within the two meters sampled. In the third series, no such gradients were found. The exact nature of these gradients remains a problem for future work.

7. No significant difference in variability of catches was observed with different sizes of nets. There is indication that the smaller nets caught less than would be indicated by the ratios of their openings to that of the 75 cm. net. Thus the 30.5 cm. net caught a fraction 0.122 of the 75 cm. net catch, against an expected ratio of 0.165; and that the 12.7 cm. net caught a fraction 0.0210 against an expected 0.0285.

8. The proportions of different groups (including sagittae, amphipods and large copepods) caught by the various nets did not vary in a manner to indicate differential selection with net size, with the possible exception of *Sagitta*, as to which the evidence is not conclusive. We may therefore conclude that under the conditions of the present investigation our smallest net is as reliable for the types of plankton considered as nets of more usual size.

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APPENDIX

THE ESTIMATION OF VARIANCE ARISING FROM DIFFERENT SOURCES

The problem of estimating the separate components of variability occupies a central position in this paper. The method we have used is a straightforward extension of the suggestions of R. A. Fisher in his "Statistical Methods for Research Workers," § 40. We now set out the assumptions made and the procedure used.

Assume that we have data divided into k sets of m observations each. Let x_{ij} be the jth observation in the ith set. We assume that the variability of x_{ij} about some hypothetical "true value" μ is due (a) to a component of random variation common to all the members of the ith set and (b) to a component of random variation peculiar to this particular observation. We assume further that these two components of variation are independent in the probability sense, and that their effects are additive. Then we can write

$$x_{ij} = \mu + \varepsilon_i + \eta_{ij}$$

where ε and η are random variables subject to some probability law. Their mean values we assume to be zero; we wish to make estimates of their mean squares. We do not know the "true value" μ, and therefore cannot determine the deviations ε_i and η_{ij} directly. But it is shown in elementary works on probability that if $u_1, u_2, \ldots u_n$ are n values of a random variable

whose true mean is U and whose true variance is σ^2, then ($\bar{u}$ being the mean of the observed values) the mathematical expectation of

$$S\,(u_i - \bar{u})^2 = (n - 1)\sigma^2.$$

Hence, if we divide (the sum of the squares of the deviations of the set from their mean) by (their total number less one) we have a quantity whose mathematical expectation is σ^2.

We may apply the same reasoning by which this result is established to the more complicated case of two categories of variation. It may readily be shown that if σ_ϵ^2 and σ_η^2 are the variances of ε and η, then the following relations hold (where $E\{\ \}$ denotes mathematical expectation):

$$E\{S_{ij}(x_{ij} - \bar{x}_i)^2\} = k(m - 1)\sigma_\eta^2$$

$$E\{mS_i(\bar{x}_i - \bar{x})^2\} = (k - 1)m\sigma_\epsilon^2 + (k - 1)\sigma_\eta^2$$

$\bar{x}_i$ and $\bar{x}$ being the mean of the ith set and the general mean, respectively. Hence we can reach estimates of σ_η^2 and σ_ϵ^2.

For practical computation, it is convenient to note that the expressions whose expectations have been given are simply the "within sets" and "between sets" sums of squares in the ordinary analysis of variance table. The arithmetical convenience of the analysis of variance computations is great; and we have therefore set up our work in this form.

It is perhaps worth pointing out that these relations do not involve any assumption as to the form of probability distribution except those explicitly made above. In particular, no assumption of "normality" has been made. In this respect our use of the analysis of variance differs from that in common practice. The difference, of course, lies in the fact that the analysis of variance is commonly used to provide a significance test, while we use it as a means of estimation.

In more complicated situations, such as arise with more than a single classification into sets, the relations are naturally more complex; but the same basic principles govern. Suppose, for example, that we have a set of hauls, in each of which we have two nets. For concreteness, suppose 10 hauls, with 6 groups enumerated. The analysis of variance table, together with the quantities of which each mean square is an estimate, will be:

	D.F.	*Expectation of mean square*
Total	*119*	
Groups	5	
Hauls	9	$12\,\sigma_H^2 + 2\,\sigma_{GH}^2 + 6\,\sigma_{HN}^2 + \sigma_{GHN}^2$
$G \times H$	45	$2\,\sigma_{GH}^2 + \sigma_{GHN}^2$
Net	1	
$G \times N$	5	$10\,\sigma_{GN}^2 + \sigma_{GHN}^2$
$H \times N$	9	$6\,\sigma_{HN}^2 + \sigma_{GHN}^2$
$G \times H \times N$	45	σ_{GHN}^2

In building these mean squares, we have assumed that variation corresponding to each σ^2 actually exists. This assumption naturally should be tested. The use of Fisher's Z test, or Snedecor's F test, is evidently appropriate. These (equivalent) tests actually supply a criterion by which we can judge whether the existence of any particular is established by the evidence. If we decide that one or other of the σ^2 is zero or negligible,—which amounts to deciding that variation from a particular source is negligible,—we may regroup our analysis accordingly to estimate the remaining σ^2.

With data divided into sets with unequal numbers the situation is somewhat more complicated, and in extreme cases the algebra may become very heavy. For this reason, among others, it is advisable to keep the ultimate analysis in mind in planning experiments. We give here the case of N observations in k sets, the number of observations in the ith set being n_i.

The usual analysis of variance table will be:

	D.F.	*Sum of squares*
Total	$N - 1$	$S_{ij}\,(x_{ij} - \bar{x})^2$
Between sets	$k - 1$	$S_i n_i\,(\bar{x}_i - \bar{x})^2$
Within sets	$N - k$	$S_{ij}\,(x_{ij} - \bar{x}_i)^2$

It can now be shown, by straighforward but somewhat lengthy algebra, that these sums of squares have the following mathematical expectations (σ_ϵ^2 and σ_η^2 having their previous significance):

$$E\,\{S_{ij}(x_{ij} - \bar{x})^2\} = \sigma_\epsilon^2\left(N - \frac{Sn_i^2}{N}\right) + \sigma_\eta^2(N - 1)$$

$$E\,\{S_i\, n_i(\bar{x}_i - \bar{x})^2\} = \sigma_\epsilon^2\left(N - \frac{Sn_i^2}{N}\right) + \sigma_\eta^2(k - 1)$$

$$E\,\{S_{ij}(x_{ij} - \bar{x}_i)^2\} = \qquad\qquad \sigma_\eta^2(N - k)$$

From these results we can evidently get our required estimates of σ_ϵ^2 and σ_η^2.

TABLE I

Series I. Oblique Hauls, 30 m. to Surface, Net Raised 3 m. Every Minute. 2 Scrim (10 strands/cm.) Nets, 75 cm. Diameter, Used in Rotation: AABBAA, etc. Hauls 220a–220l. Aug. 24, 1936. Location: Whistle Buoy at Western Entrance to Vineyard Sound (Station 3). Depth to Bottom: 38 m. Figures Are Estimated Totals in the Catch. Figures in Parentheses Are Number of 29 cc. Samples on Which Estimate Is Based. Dilution for C. finmarchicus = 2000 cc.; for C. typicus, 8000 cc.

Net	*C. finmarchicus Cop. IV*	*C. finmarchicus Cop. V*	*C. typicus adult ♀*	*C. typicus adult ♂*
A	(5) 895	(5) 1520	(2) 43300	(3) 11000
A	(5) 540	(5) 1610	(2) 32800	(4) 8600
B	(5) 1020	(5) 1900	(2) 28800	(4) 8260
B	(5) 470	(5) 1350	(2) 34600	(3) 9830
A	(5) 428	(5) 980	(2) 27800	(4) 7600
A	(4) 620	(4) 1710	(2) 32800	(3) 9650
B	(5) 760	(4) 1930	(2) 28100	(4) 8900
B	(5) 537	(4) 1960	(3) 18900	(5) 6060
A	(4) 845	(4) 1840	(2) 31400	(3) 10200
A	(5) 1050	(3) 2410	(2) 39500	(2) 15500
B	(5) 387	(5) 1520	(2) 29000	(4) 9250
B	(5) 497	(5) 1685	(4) 22300	(4) 7900
Mean	671	1701	30775	9396
Range	663	1480	24400	9440

TABLE II

Logarithms of Estimated Catches. Series I

	C.f. IV	*C.f. V*	*C.t., ♀*	*C.t., ♂*	*Haul Mean*
	2.95	3.18	4.64	4.04	3.70
	2.73	3.21	4.52	3.93	3.60
	3.01	3.28	4.46	3.92	3.67
	2.67	3.13	4.54	3.99	3.58
	2.63	2.99	4.44	3.88	3.48
	2.79	3.23	4.52	3.98	3.63
	2.88	3.29	4.45	3.95	3.64
	2.73	3.29	4.28	3.78	3.52
	2.93	3.26	4.50	4.01	3.68
	3.02	3.38	4.60	4.19	3.80
	2.59	3.18	4.46	3.97	3.55
	2.70	3.23	4.35	3.90	3.54
Species Mean	2.80	3.22	4.48	3.96	
Range	.43	.39	.36	.41	

TABLE III

SERIES III. VERTICAL HAULS, 31 M. TO SURFACE AT 0.6 M./SEC. SCRIM NETS 75 CM. AND 30.5 CM. USED ALTERNATELY. HAULS 301 A–H. JUNE 29, 1937. LOCATION 4 MILES W × N OF GAY HEAD. DEPTH TO BOTTOM 31.5 M. FIGURES ARE ESTIMATED TOTALS IN THE CATCH. 1/69 OF CATCH COUNTED WITH 75 CM. NET; TOTAL CATCH COUNTED WITH 30.5 CM. NET.

	Haul	*Limacina retroversa*	*Centropagus typicus* ♀	*C. hamatus* ♀	*C. typicus* ♂	*P. minutus* ♂	*T. discaudatus* ♀
	1	1850	442	924	318	815	345
75 cm.	3	1880	940	1210	653	594	635
net	5	897	649	1710	788	525	394
	7	925	593	745	386	221	166
	2	157	86	68	43	30	35
30.5 cm.	4	247	80	192	61	66	35
net	6	184	138	196	105	40	44
	8	146	206	180	141	71	36

TABLE IV

SERIES IV. VERTICAL HAULS, 35 M. TO SURFACE AT 0.5–0.9 M./SEC. SCRIM NETS, 75 CM., 30.5 CM., AND 12.7 CM. IN DIAMETER USED IN SUCCESSION. HAULS $312A_1$–$312C_{10}$. AUG. 10, 1937. LOCATION: WHISTLE BUOY AT WESTERN ENTRANCE TO VINEYARD SOUND. DEPTH TO BOTTOM: 42 M. FIGURES ARE ESTIMATED TOTALS IN THE CATCH BASED ON INDICATED ( ) NUMBER OF 29 CC. SAMPLES. (T) INDICATES TOTAL COUNT. DILUTED FOR C. TYPICUS IN 75 CM. NET CATCH 2000 CC. IN 30.5 CM. NET CATCH 1000 CC.

	75 cm. Net (No. 2)				*30.5 cm. Net (No. 25)*				*12.7 cm. Net (No. 21)*			
	C. typicus adult ♂–♀		*S. elegans all over .5 cm. long*		*C. typicus adult* ♂–♀		*S. elegans all over .5 cm. long*		*C. typicus adult* ♂–♀		*S. elegans all over .5 cm. long*	
1)	(2)	14750	(T)	123	(5)	1115	(T)	17	(T)	241	(T)	0
2)	(2)	19200	(T)	150	(4)	2010	(T)	19		341		3
3)	(2)	19640	(T)	190	(3)	2705	(T)	24		568		1
4)	(2)	8950	(T)	34	(2)	2550	(T)	7		240		0
5)	(2)	24800	(T)	63	(2)	1960	(T)	8		564		0
6)	(4)	1880	(T)	12	(5)	798	(T)	1		496		1
7)	(2)	15900	(T)	44	(2)	2150	(T)	5		334		0
8)	(4)	1850	(T)	14	(2)	2390	(T)	10		246		1
9)	(2)	13800	(T)	40	(4)	1075	(T)	3		154		0
10)	(2)	18400	(T)	90	(2)	1890	(T)	4		407		3
Total		139000		760		18600		98		3591		9

TABLE V

DATA FROM GARDINER'S TABLE II. VERTICAL HAULS, 80 M. TO SURFACE. ORGANISMS PER METER DEPTH.

Time	*Calanus*	*Temora*	*Ps. and Paracalanus*	*Other Organisms*
20:23	56	22	47	21
22:00	69	13	61	31
22:05	46	15	55	82
22:20	37	8	84	12
1:25	36	19	47	10
1:30	25	15	66	16
1:37	98	44	159	54
1:45	64	38	51	66
1:55	58	20	112	42
2:45	92	15	111	43
2:54	139	26	132	35
3:05	139	28	142	50
3:15	95	31	193	61
3:23	155	50	134	40
3:50	95	36	169	52
3:55	159	61	139	85
4:02	156	43	206	87
4:08	150	49	208	89
4:15	166	57	237	84
4:20	91	46	229	40
4:33	101	43	161	62
5:00	89	46	73	38
5:07	111	59	77	28
5:15	72	61	102	44
5:20	90	30	89	56
5:25	108	45	154	49
5:35	151	53	132	48
6:45	104	44	192	54
7:00	101	71	154	26
7:08	146	84	231	78
7:12	113	74	199	72
7:20	115	62	137	51
7:30	111	58	234	58
7:36	143	44	169	48
7:45	114	50	151	66
7:50	102	47	164	78

} Grouping in 10 minute intervals.

] Grouping in hour intervals.

TABLE VI

(From Künne, 1933, Table 8.) Vertical Hauls; H = Hensen Egg Net; L = Helgoland Larva Net. Figures Are Total Counts.

Series	*Net*	*Small Medusa*	*Terebellid larvae*	*Tomopteris*	*Calanus*	*Decapod larvae*
62	H	354	8	54	97	51
	L	1521	22	200	1275	1398
	L	1451	19	257	618	603
	H	489	10	63	182	146
	H	375	12	26	143	107
63	L	1384	23	193	745	411
	L	1414	36	113	742	566
	H	473	3	31	195	223
	H	437	2	30	182	144
64	L	1769	26	104	852	857
	L	1948	31	92	958	820
	H	442	4	29	210	264
	H	326	4	24	155	94
65	L	1437	24	92	566	325
	L	1522	20	63	551	318
	H	415	7	39	163	141

		Small Medusae	*Calanus*	*Decapod larvae*	*Fish Eggs*
	H	29	26	24	64
73	L	127	79	43	298
	L	92	90	73	301
	H	21	32	26	68
	H	19	22	21	90
74	L	85	119	132	340
	L	92	114	144	224
	H	27	34	21	72
	H	29	30	46	80
75	L	35	93	160	252
	L	45	115	178	360
	H	11	23	33	74
	H	6	20	48	53
76	L	56	120	231	251
	L	63	106	247	221
	H	11	34	55	51

TABLE VII

SERIES V. HORIZONTAL HAULS, 15 MIN. AT 2 KNOTS. SCRIM NETS 12.7 CM. IN DIAMETER (NOS. 22 AND 23) AT 29 AND 31 M., AND SCRIM NET 75 CM. IN DIAMETER (NO. 2) AT 30 M. TOWED SIMULTANEOUSLY. HAULS $324A_1$–$324C_{10}$ AUGUST 26, 1937. LOCATION: WHISTLE BUOY NO. 6 OFF CHATHAM. DEPTH TO BOTTOM: 35 N. FIGURES ARE ESTIMATED TOTALS IN THE CATCH BASED ON INDICATED ( ) NUMBER OF SAMPLES. (T) = TOTAL COUNT. FOR NETS NOS. 22 AND 23: DILUTION 1000 CC. SAMPLE SIZE 58 CC.; FOR NET NO. 2 DILUTION 10,000 CC. SAMPLE SIZE 29 CC.

	Calanus finmarchicus cop. V	*C. finmarchicus adult ♀*	*Metridia luceus adult ♀*	*Centropages typicus adult ♂ ♀*	*Euthemisto juv.*
No. 22	860 (4)	400 (4)	492 (4)	1100 (4)	48 (4)
No. 2	50500 (2)	21000 (2)	17400 (2)	55500 (2)	2490 (5)
No. 23	403 (5)	217 (5)	259 (5)	1150 (2)	15 (T)
No. 23	1110 (2)	266 (5)	855 (3)	810 (3)	87 (5)
No. 2	54500 (2)	15800 (2)	33000 (2)	25200 (2)	2800 (5)
No. 22	450 (4)	135 (5)	380 (5)	450 (4)	24 (5)
No. 22	1400 (2)	218 (5)	1850 (2)	790 (3)	148 (5)
No. 2	71000 (2)	8950 (5)	79000 (2)	25500 (2)	2700 (5)
No. 23	1050 (2)	156 (5)	1670 (2)	760 (3)	103 (5)
No. 23	344 (5)	45 (5)	387 (5)	278 (5)	93 (5)
No. 2	27800 (2)	4950 (5)	32000 (2)	19600 (2)	2420 (5)
No. 22	366 (5)	66 (5)	545 (4)	485 (4)	58 (5)
No. 22	442 (5)	79 (5)	183 (5)	705 (3)	48 (5)
No. 2	19800 (2)	3030 (5)	13200 (3)	33500 (2)	965 (5)
No. 23	200 (5)	41 (5)	141 (5)	560 (4)	14 (5)
No. 23	705 (3)	120 (5)	960 (3)	240 (5)	65 (5)
No. 2	81000 (2)	10500 (4)	72000 (2)	20500 (2)	4400 (5)
No. 22	1440 (2)	131 (5)	1310 (2)	495 (4)	93 (5)
No. 22	1170 (2)	110 (5)	5780 (2)	920 (3)	65 (5)
No. 2	59700 (2)	6230 (5)	203000 (2)	20700 (2)	1070 (5)
No. 23	1200 (2)	107 (5)	4350 (2)	297 (5)	59 (5)
No. 23	276 (5)	38 (5)	1060 (2)	480 (4)	55 (5)
No. 2	18300 (2)	1660 (5)	59000 (2)	20300 (2)	670 (5)
No. 22	380 (5)	45 (5)	1090 (2)	410 (5)	35 (5)
No. 22	965 (2)	72 (5)	1900 (2)	396 (5)	90 (5)
No. 2	46000 (2)	4200 (5)	57500 (2)	13600 (3)	1930 (5)
No. 23	835 (3)	69 (5)	805 (3)	350 (5)	38 (5)
No. 23	1060 (2)	114 (5)	400 (5)	440 (4)	55 (5)
No. 2	52500 (2)	5050 (5)	17100 (3)	17600 (2)	2500 (5)
No. 22	610 (3)	41 (5)	332 (4)	245 (5)	28 (5)

TABLE VIII

SERIES VI. HORIZONTAL HAULS, 10 MIN. AT 2 KNOTS. SCRIM NETS 12.7 CM. IN DIAMETER (NO. 21 WITH VOLUME METER AND NO. 23) AT 29 AND 31 M., AND SCRIM NET 75 CM. IN DIAMETER (NO. 2) AT 30 M. TOWED SIMULTANEOUSLY. HAULS $327A_1$–$327C_{11}$. SEPTEMBER 9, 1937. LOCATION: CAPE COD BAY, OFF CANAL ENTRANCE. DEPTH TO BOTTOM 36 M. FIGURES ARE ESTIMATED TOTALS IN THE CATCH BASED ON INDICATED ( ) NUMBER OF SAMPLES. DILUTIONS AND SAMPLES AS IN SERIES V.

	C. finmarchicus		*Metridia*	*C. typicus*	*Euthemisto*	*Sagitta*	*Volume*
	cop. V.	*adult* ♀	*lucens*	♂ ♀	*juv.*	*elegans*	*meter*
No. 21	1730 (4)	169 (5)	36 (8)	194 (5)	235 (5)	45 (T)	—
No. 2	81500 (4)	8300 (4)	2760 (5)	9500 (4)	19900 (4)	3020 (4)	
No. 23	684 (7)	69 (5)	65 (5)	72 (5)	118 (5)	7 (5)	
No. 23	3200 (2)	303 (5)	59 (5)	149 (5)	905 (2)	100 (2)	
No. 2	84500 (2)	7000 (5)	2760 (5)	9150 (4)	12800 (4)	4350 (5)	
No. 21	1340 (2)	110 (5)	260 (5)	230 (5)	155 (5)	62 (5)	1384
No. 21	1160 (2)	76 (5)	41 (5)	256 (5)	124 (5)	117 (5)	—
No. 2	51500 (2)	2700 (5)	3700 (5)	6500 (5)	9650 (4)	6060 (5)	
No. 23	1220 (2)	73 (4)	263 (4)	164 (4)	152 (5)	76 (5)	
No. 23	990 (2)	58 (5)	79 (5)	169 (5)	259 (5)	110 (5)	
No. 2	42300 (2)	2480 (5)	18300 (2)	6200 (5)	4420 (5)	6600 (5)	
No. 21	785 (3)	35 (5)	605 (3)	276 (5)	107 (5)	65 (5)	1305
No. 21	1725 (2)	176 (5)	62 (3)	228 (5)	262 (5)	100 (5)	1644
No. 2	Haul lost						
No. 23	1940 (2)	166 (5)	89 (5)	114 (5)	272 (3)	48 (5)	
No. 21	735 (3)	79 (5)	14 (5)	169 (5)	180 (5)	27 (5)	1334
No. 2	36600 (3)	2280 (5)	345 (5)	5500 (5)	5100 (5)	1240 (5)	
No. 23	930 (2)	79 (5)	45 (5)	117 (5)	280 (5)	27 (5)	
No. 23	1200 (2)	145 (5)	17 (5)	104 (3)	230 (5)	31 (5)	
No. 2	29400 (2)	1860 (5)	895 (5)	4200 (5)	5050 (5)	1240 (5)	
No. 21	706 (3)	38 (5)	45 (5)	121 (5)	193 (5)	52 (5)	1392
No. 21	1350 (2)	73 (5)	204 (5)	280 (5)	320 (5)	20 (5)	1531
No. 2	49000 (2)	3100 (5)	12400 (3)	5450 (5)	11700 (4)	1040 (5)	
No. 23	690 (3)	41 (5)	390 (5)	117 (5)	250 (5)	7 (T)	
No. 23	950 (2)	97 (5)	190 (5)	114 (5)	328 (5)	24 (5)	
No. 2	38500 (2)	2140 (5)	12600 (3)	4700 (5)	10600 (4)	415 (5)	
No. 21	575 (3)	38 (5)	760 (3)	169 (5)	120 (5)	6 (T)	1372
No. 21	1430 (2)	90 (5)	262 (5)	131 (5)	500 (5)	27 (T)	1741
No. 2	59000 (2)	1725 (5)	22800 (5)	3700 (3)	19000 (3)	690 (4)	
No. 23	1070 (2)	79 (5)	880 (2)	107 (5)	354 (5)	5 (T)	
No. 23	Haul lost						
No. 2	49000 (2)	1725 (5)	1930 (5)	4550 (5)	7050 (5)	3040 (5)	
No. 21	1060 (2)	62 (5)	338 (5)	159 (5)	148 (5)	41 (5)	1131

TABLE IX

Series VII. Horizontal Hauls. Scrim Nets 12.7 cm. in Diameter (no. 21 with Volume Meter and no. 23) Towed Simultaneously at 29 and 30 m. Series Made Immediately after Series VI, Same Procedure

Net	*Calanus cop. V*	*Calanus adult* ♀	*Metridia* ♀	*C. typicus* ♂ ♀	*Euthemista*	*Sagitta*
21	1320 (2)	93 (5)	21 (5)	190 (5)	117 (5)	69 (5)
23	1130 (2)	152 (5)	14 (5)	121 (5)	190 (5)	59 (5)
23	563 (3)	45 (2)	14 (5)	179 (5)	79 (5)	20 (T)
21	934 (2)	72 (5)	31 (5)	193 (5)	114 (5)	38 (5)
21	493 (4)	14 (5)	124 (5)	293 (5)	110 (5)	7 (T)
23	290 (5)	24 (5)	55 (5)	134 (5)	48 (5)	3 (T)
23	193 (5)	17 (5)	221 (5)	162 (5)	131 (5)	1 (T)
21	586 (3)	34 (5)	355 (5)	217 (5)	93 (5)	5 (T)
21	586 (3)	45 (5)	217 (5)	121 (5)	97 (5)	5 (T)
23	598 (3)	24 (5)	286 (5)	176 (5)	103 (5)	8 (T)

TABLE X

Series II. Horizontal Hauls at 13 m. One Open Scrim Net (10 strands/cm.), 75 cm. Diameter. Hauls 133 a–j. August 9, 1935. Location: Whistle Buoy at Western Entrance to Vineyard Sound (Station 3). Depth to Bottom: 38 m. Figures Are Estimated Totals in the Catch. Figures in Parentheses Are Number of 29 cc. Samples on Which Estimate Is Based. Dilution for C. finmarchicus = 3000 cc., except in One Instance (133b. C. finmarchicus V, dil. = 6000 cc.) for C. typicus and C. hamatus = 300 cc.

Calanus finmarchicus			*Centropages typicus*		*Centropages hamatus*
IV	*V*	*adult* ♀	*adult* ♀	*adult* ♂	*adult* ♀
(4) 3410	(2) 12900	(4) 1110	(4) 1880	(a)	(a)
(2) 8700	(2) 14700	(5) 825	(5) 2410	(5) 845	(5) 845
(4) 2780	(3) 4180	(5) 415	(5) 1300	(5) 165	(5) 226
(3) 4750	(2) 8550	(5) 950	(5) 2000	(5) 868	(5) 279
(5) 1300	(5) 2080	(5) 290	(5) 847	(5) 394	(5) 186
(3) 4200	(2) 9250	(5) 1135	(5) 1780	(5) 620	(5) 600
(5) 2140	(5) 3200	(5) 370	(5) 1160	(5) 310	(5) 206
(3) 4800	(2) 5840	(5) 535	(5) 1740	(5) 890	(5) 1390
(5) 1590	(5) 4800	(5) 725	(5) 1034	(5) 165	(5) 330
(2) 5740	(2) 6350	(5) 660	(4) 2800	(5) 1300	(5) 745

(a) Not enumerated.

Contribution No. 245

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The Present Evidence on the Importance of Lateral Mixing Processes in the Ocean[1]

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Both in meteorology and in oceanography the study of isentropic (or lateral or horizontal) mixing processes has received much attention in this country during the last four years. Previously it was quite generally accepted that these processes were of negligible importance in nearly all problems ([2]), because the horizontal gradients of diffusible properties are normally far less than the vertical gradients. Four years' intensive work still does not suffice to answer definitely the question: "How important are isentropic mixing processes?" But the question is of such great interest that meteorologists may appreciate a résumé of the pertinent oceanographic evidence.

§1. The possible importance of isentropic mixing processes was first brought to light in Rossby's (1936) paper on the "Dynamics of steady ocean currents in the light of experimental fluid mechanics." This starts with a discussion of the currents in the North Atlantic Ocean, which for simplicity are assumed to constitute a single great anticyclonic circulation. The nearly permanent trade winds and the less permanent westerlies over the North Atlantic exert an anticyclonic torque on the surface waters, and the same is the case for the South Atlantic. The surface currents show a definite anticyclonic motion, coinciding roughly with the superposed wind system. ([3]) The whole current system is, we believe, maintained chiefly by the wind. Since the great anticyclonic circulation does not gradually accelerate, the torque exerted by the wind must be balanced by an equal cyclonic torque.

According to Ekman's classic theory of currents in a homogeneous ocean, the cyclonic torque is supplied by friction between the deep currents and the ocean floor. If, at any locality in the ocean, bottom friction is to balance wind friction, it can be shown that the current near the bottom must have about the same speed as the pure drift current at the sea surface, or 2 to 3 percent of the wind speed. The accumulating information on deep currents, however, fails to reveal mean velocities of this magnitude. It can further be shown that, in order to maintain a deep current of the necessary magnitude in a nonhomogeneous ocean, the total surface velocity would have to be several times the observed magnitude.

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[1]Read at the Cambridge Seminar, December 18, 1939. Contribution No. 245 of the Woods Hole Oceanographic Institution.

[2]For instance see Ekman (1923, p. 2). References are listed at end of article.

[3]For charts of the surface winds and surface currents of the Atlantic Ocean see, for instance, Schott (1926, Tafel XV and Tafel XX).

To be sure, it is not altogether correct to picture the great anticyclonic circulations as simple closed systems, because, for instance, considerable water from both the North and South Atlantic circulations passes through the Central American seas, where bottom friction through the straits is undoubtedly greater than in the open ocean (see § 6, below). But even in these straits the average velocities near the bottom appear to be weak. Thus I can find nothing faulty in Rossby's deduction that ordinary bottom friction is entirely inadequate to balance the anticyclonic torque exerted by the wind.

The only other possible cyclonic torque is lateral friction exerted by the continental slopes, as well as by the sides of straits through which branches of the anticyclonic circulation passes. From this broad analysis it follows at once that lateral shearing stresses are of great importance in dynamic oceanography.

§ 2. Several estimates have been made of the coefficients of lateral eddy viscosity and lateral eddy diffusivity in the ocean.

The first of these is Sverdrup's (1938, pp. 289-290) value for the diffusion of salt and heat between the currents off the California coast. See Figure 1. "It has repeatedly been found that in this area a sub-surface current runs north close to the coast, whereas at some distance from the coast the water flows south." The original high temperature and high salinity of the inshore current decreases downstream, the original low temperature and salinity of the offshore current increases downstream, apparently due to lateral mixing between the two currents. From this distribution of the identifying properties and from the difference of the two velocities Sverdrup has found the lateral eddy diffusivity to be 2×10^6 cm^2 sec^{-1}. The final report on this

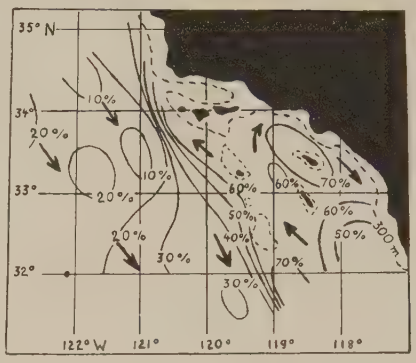

Fig. 1. Percentage content of "southern" water at a depth of 300 meters on May 5-13, 1937, off southern California. Arrows indicate direction of flow. (After Sverdrup, 1938, Figure 14.)

study has not yet appeared, and I am not sure one is fully justified in assuming that a steady state is maintained with the axial gradients of temperature and salinity being due solely to lateral diffusion.

§ 3. At a depth of about 100 meters a core of relatively saline, warm water coincides with the eastward-flowing Atlantic Equatorial Counter Current, and its properties decrease downstream. This core appears two-dimensionally on the isentropic chart in Figure 2, and the vertical salinity maximum is even more pronounced (Montgomery, 1939, Abb. 3 and Abb. 4). For present purposes it appears fully permissible to regard conditions as conforming to a steady state, so the downstream decrease is definitely the result of diffusion—either vertical or lateral or both. The decrease can be accounted for by a vertical eddy diffusivity alone of 0.4 cm^2 sec^{-1}, or by a lateral eddy diffusivity alone of 40×10^6 cm^2 sec^{-1}, as computed from the salinity distribution and the speed of the salt core (about 30 cm sec^{-1}).

The computed vertical coefficient is small, as is to be expected since the core lies in the *Sprungschicht*, or layer of maximum vertical stability. But there is reason to believe that not

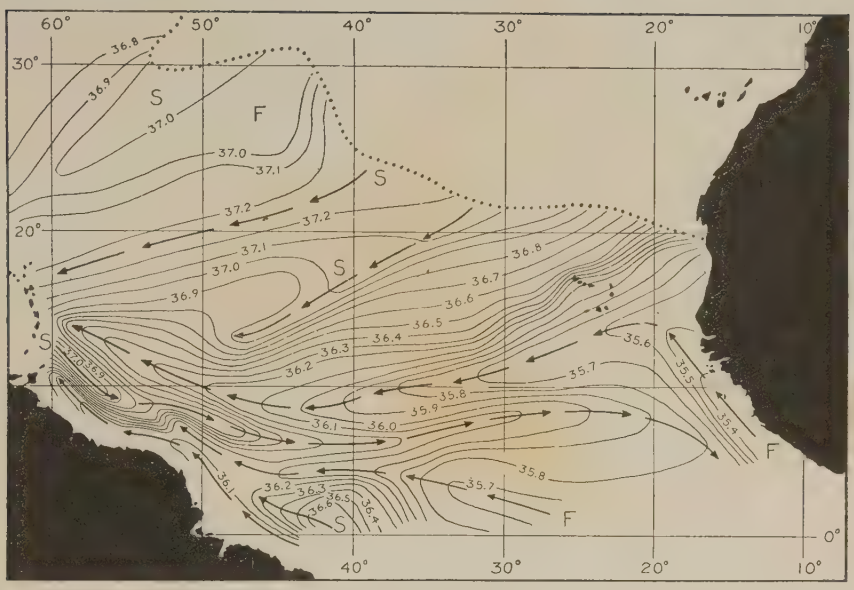

FIG. 2. Isentropic chart of salinity (parts perthousand) on the $\sigma_t = 25.5$-surface in the southern North Atlantic Ocean. This surface cuts the sea surface along the dotted line, south of which it lies mostly between 75 and 125 meters depth. The arrows directed eastward represent the axis of the salt ("S") equatorial counter current flowing between the flanking bands of fresher water ("F"). (Montgomery, 1939, Abb. 1.)

even this small coefficient can occur here, for the ratio of the square of the vertical shear to the stability is so small that according to Richardson's criterion no vertical turbulence can exist. (Defant, 1936, pp. 294-299).

Furthermore, in another region where the vertical shear is greater in every case (with one exception) and the stability much less than in the Counter Current so that conditions are much more favorable for vertical mixing, Taylor has determined values of the vertical eddy diffusivity of 0.04 to 0.6 $cm^2\ sec^{-1}$. So both the criterion and this comparison indicate that vertical diffusion is inadequate to explain the downstream decrease of salinity, that it must therefore be ascribed to lateral diffusion with a coefficient of about 40×10^6 $cm^2\ sec^{-1}$.

§ 4. Montgomery and Palmén ([4]) have found that the trade winds, by continually exerting a westward stress on the sea surface, produce a westward ascent of sea level along the equator. This slope amounts to about 4 cm per thousand km, and the accompanying pressure gradient extends down to about 150 meters in the Atlantic Ocean. The equatorial counter currents are found in the doldrums and apparently result simply as a downslope flow in this zone where the winds maintaining the slope are absent. Here again, as in the case of the great anticyclonic circulations, there must be a retarding force, for speeds corresponding to free fall are not attained. The retarding force may be friction with

[4]R. B. Montgomery and Erik Palmén, "Contribution to the question of the equatorial counter current," in preparation.

the underlying and more stagnant water, but it seems more likely to be lateral friction with the westward-flowing equatorial currents which flank the counter current. If this is the case, opportunity is afforded for estimating the lateral eddy viscosity, and the value 70×10^6 cm^2 sec^{-1} has been obtained.

§ 5. In each of the items presented above the importance of isentropic mixing processes rests on proof of the impotence of vertical mixing, which was not definitely established except for the great anticyclonic circulations. It is therefore of interest to mention the growing evidence that the water masses found in the ocean are not the result of non-isentropic mixing (except for mixing at the ocean boundaries).

The salinity distribution over the surface of the Atlantic Ocean ([5]) has two maxima located somewhat nearer the equator than the axes of the two great anticyclonic circulations. One might expect to find these maxima propagated downward by vertical mixing, and indeed the surfaces of 200, 400, 600 meters depth do show salinity distributions, (Wüst und Defant, 1936, Beilage LXII, etc.) roughly parallel to that at the sea surface. Until recently, in fact, these

[5]For instance see Böhnecke (1936, Beilage XXVII) and the inset chart in Figure 3.

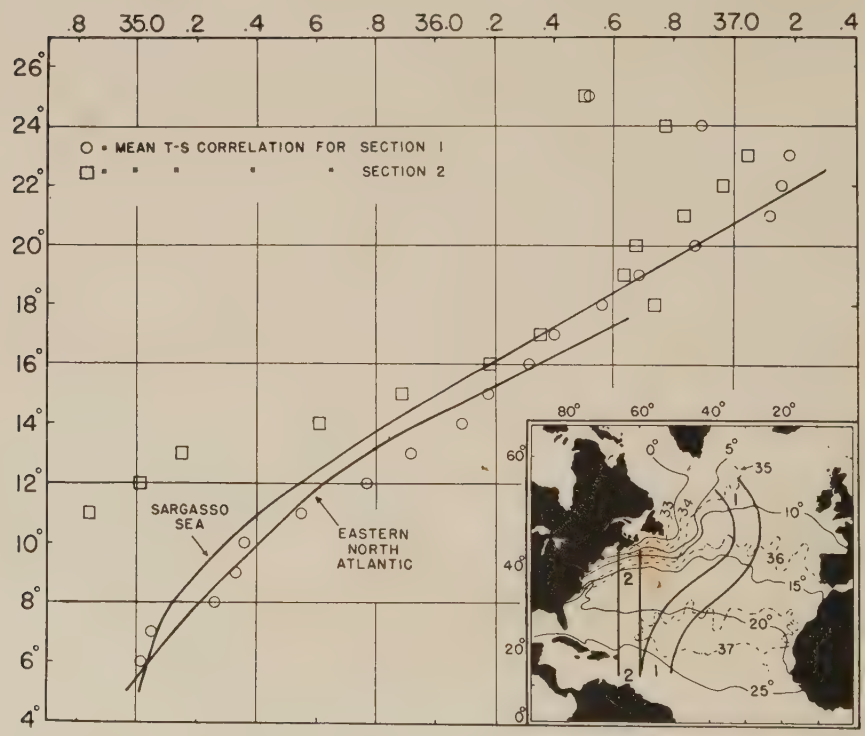

FIG. 3. Characteristic diagram of temperature (°C.) vs. salinity (parts per thousand) for certain waters of the North Atlantic Ocean. The points on the diagram represent the characterisics in March of the surface waters along the two bands shown in the inset chart. Each of the two curves represents the characteristics of a vertical column of water in the open Atlantic. On the inset chart appear some isolines of temperature and of salinity. (Iselin, 1939, Fig. 1.)

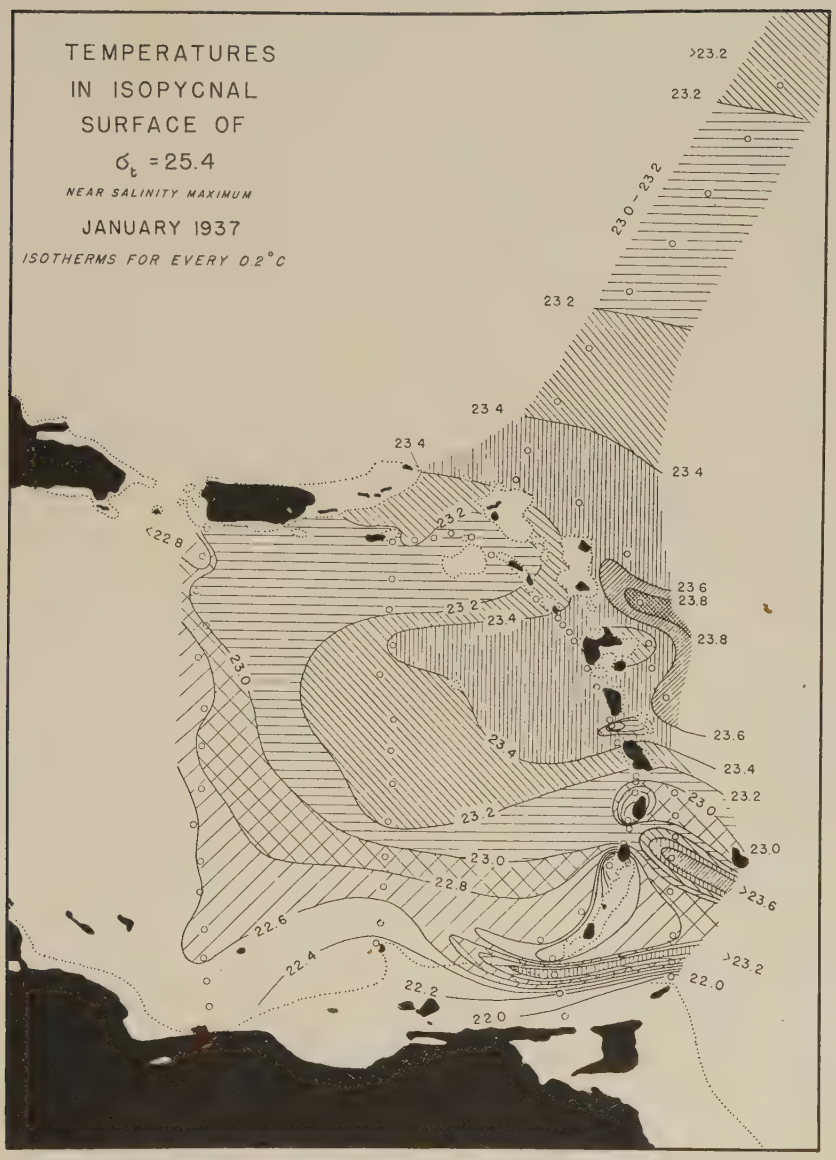

FIG. 4. Isentropic chart of temperature on the $\sigma_t = 25.4$-surface in the eastern Caribbean Sea and adjacent waters of the Atlantic Ocean. Dotted line is 100 fathom contour. On such a chart salinity is parallel to temperature, so the low temperatures surrounding the Windward Islands signify low salinities. (Parr, 1938, Figure 12.)

were ascribed either to mass vertical sinking or to vertical diffusion, but this explanation is now known to be incorrect (Montgomery, 1938, p. 37). On surfaces of constant potential density, as far as present experience

goes, no permanent salinity maxima occur except at the boundaries, i. e. intersections with the wind-stirred surface layer or with the lithosphere (Montgomery, 1938, p. 45). Almost undiluted water from the salinity maxima at the sea surface is found below the surface layer, but only at the same potential density as the surface maxima.

This type of evidence is neatly illustrated by Iselin's (1939) comparison of the temperature-salinity correlation for the winter surface waters along the central band of the North Atlantic with the correlation for a vertical in the Sargasso Sea region, shown in Figure 3. The agreement indicates that vertical mixing need not be evoked to account for the waters in the Sargasso Sea.

§ 6. Two regions have come to light where the dominence of lateral over vertical mixing would be definitely proven if our interpretation of the kinematics were certain.

One of these is revealed in Figure 4, Parr's (1938) isentropic chart of temperature on the $\sigma_t = 25.4$ – surface, which coincides with the salinity maximum layer. The low salinities found surrounding the Windward Islands apparently result from non-isentropic, shoal-water mixing with the fresher waters above and below. If there is a general mass westward flow through the whole region, as generally assumed, it is seen that on reaching open water again in the Caribbean Sea these low values are wiped out—which can be ascribed only to lateral mixing.

§ 7. The other of these regions is revealed by Figure 2, which was drawn for practically the same surface as Parr's and again represents the salinity maximum layer. Flanking the Atlantic Equatorial Counter Current on the north is a long fresh band, interpreted as coinciding with the swiftest part of the North Equatorial Current. Salinity increases westward, or downstream, which again can be ascribed only to lateral mixing, as vertical mixing would decrease the salinity (Montgomery, 1938, pp. 35-36). However, the flow of this fresh band is not definitely known: according to the previous analysis by Defant (1936, pp. 335-342) the band occurs in water which is stagnant or moving slowly eastward, and its fresh character is the result of upwelling and vertical mixing.

§ 8. There are two cases in which it has been shown that major oceanographic patterns can be explained qualitatively on the basis of rather intense lateral or horizontal mixing.

The first of these forms the main subject of Rossby's (1936) ([6]) pioneer paper already referred to. It assigns to lateral eddy viscosity the dominant role in determining the form of the Gulf Stream, which is considered a jet stream ejected from the Straits of Florida. The concentrated momentum at the jet diffuses laterally on passing downstream. Assuming no loss of momentum, this requires not only that the stream spread, but also that the volume transport increase downstream. This in turn requires inflow from the sides, which, taking into consideration the rotation of the earth, demands a counter current on the left side. Further discussion shows that the inflow on the right side should be strongest upstream (as the Antilles Current), and that calving of large eddies may be expected downstream on the left side. While all these phenomena are qualitatively observed, Ekman (1939, pp. 46-60) has raised severe objections to the jet stream theory as applied by Rossby to the Gulf Stream.

§ 9. The second pattern mentioned is that of the temperature distribu-

[6]See also Defant (1937).

tion below 1000 meters on a north-south cross-section in the Atlantic. Sverdrup (1938, pp. 290-292) suggests that there are no permanent currents in this deep water which are of importance for the distribution of identifying properties, and thus assigns the temperature distribution to vertical and horizontal ([7]) diffusion. In other words, he assumes that at every point the heat gain by vertical diffusion equals the heat loss by horizontal diffusion.

Solving the differential equation expressing this equality, a temperature distribution is obtained which coincides roughly with the observed one. The solution is such that there is no temperature gradient and hence no heat exchange at the bottom. Heat is gained at the top, most intensely at 30°N, and lost at the ends, where Arctic and Antarctic surface cooling and convection maintain constant temperature from top to bottom. Horizontal and vertical eddy diffusivities are assumed constant and in the ratio 6×10^6, and he finds that 1 cm^2 sec^{-1} for the vertical coefficient gives a reasonable downward transport of heat from the top. ([8])

§ 10. To effect these isentropic mixing processes there must be a turbulent mechanism, at least some forms of which should be displayed directly. The individual turbulent elements which account for the isentropic mixing are too small to be resolved by the type of oceanographic measurements commonly made heretofore, but by a new technique Spilhaus ([9]) has recently obtained a few very detailed temperature cross-sections, extending to a depth of 100 meters, normal to the main stream in the region of the Gulf Stream off Montauk Point. These reveal anomalous temperatures which may be ascribed to turbulent elements of the type in question. One of his sections in particular shows an area of closed isotherms extending from 7 to 18 meters depth and 16 km long. This is intermediate in magnitude between the elements responsible for vertical mixing and the large-scale eddies which are often observed, for instance, on the left side of the Gulf Stream, and appears to be of suitable size to accomplish isentropic mixing.

§ 11. Such turbulent elements as those just described may be produced by the lateral shear of large, permanent ocean currents. This mechanism, although it might produce sufficient

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[7]Sverdrup uses the word "lateral," which I believe should be reserved for the diffusion—due to mixing across "vertical surfaces parallel to the horizontal current components" (Rossby, 1936, p. 6)—between a dominant current and the fluid flanking it. It might be added that in a stratified fluid the term "lateral mixing" has come to be further limited so as to refer specifically to isentropic mixing and not to mixing along level surfaces.

[8]This scheme has been retracted by Sverdrup (1939) subsequent to the preparation of the present article. He states (p. 198):

"A closer examination of the distribution of temperature and salinity in the South Atlantic Ocean has now been completed, but this has clearly shown that the above suggestion is not correct as far as conditions in that ocean are concerned. The results do indicate, however, that in general the processes of lateral mixing are of greater importance than those of vertical mixing."

His region of study is the western basin of the South Atlantic between 60°S and 30°S at depths between 2500 and 4000 meters, for which he has constructed a meridional section of temperature and salinity. As quoted, he finds that meridional horizontal diffusion and vertical diffusion in the absence of any mean flow cannot maintain the observed distributions in this section. He finds secondly that these distributions cannot be maintained by vertical diffusion alone in conjunction with a meridional flow, but he finds thirdly that they can be maintained by meridional horizontal diffusion alone in conjunction with a meridional flow. Supposing a flow of 1 cm sec^{-1} he arrives at a horizontal diffusivity of 100×10^6 cm^2 sec^{-1}.

Just as in the other items (§ 2 – § 8) Sverdrup's new and extremely neat analysis does not lead to results which are definitely proven, for he has neglected, without offering evidence, the effect on the temperature and salinity distributions in his meridional section not only of longitudinal flow but also of longitudinal horizontal mixing. According to his source material (Wüst und Defant, 1936, Beilage LVIII and Beilage LXXIII, etc.) the longitudinal gradients appear to be of similar magnitude to the meridional ones.

[9]A report by Athelstan F. Spilhaus on this work carried out by him at the Woods Hole Oceanographic Institution is in preparation.

lateral turbulence in regions dominated by coastal effects and by powerful currents, would probably leave large regions of the ocean, especially at great depths, quite free of any isentropic turbulence. Another mechanism has been brought to light by Rossby (1938) ([10]). He has shown theoretically that transitory surface currents, which may be produced by storms, induce transitory deep currents extending in some cases even to the bottom. Either these variable currents themselves, or lateral turbulence produced by their shear, can account for isentropic mixing in regions where there are no permanent currents.

The above items (§ 1-§ 11) summarize the oceanographic evidence on the importance of lateral mixing processes. Only Rossby's original discussion of the great anticyclonic circulations (§ 1) gives irrefutable evidence that lateral mixing is of prime importance in the ocean. The additional items point toward the same conclusion, but in each case the evidence cannot as yet be regarded complete.

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[10] See also Defant (1939).

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THE ORIGIN OF THE DIABETOGENIC HORMONE IN THE DOGFISH [1]

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It is generally regarded that the anterior lobe of the pituitary produces a diabetogenic hormone. A good deal of the evidence for this view has been obtained by injection of extracts of the various lobes of the pituitary into normal or hypophysectomized-depancreatized animals. Although posterior and intermediate lobe extracts have been found to be mildly diabetogenic, most of the diabetogenic activity is found in the extracts of the anterior lobe (Houssay, 1937). Recently, an attractive possibility has been presented by O'Donovan and Collip (1938) to the effect that the diabetogenic, ketogenic, and specific metabolic effects of pituitary extracts represent the action of the melanophore hormone, intermedin. This view not only tends to reduce the number of hypophyseal principles but also supplies a function for the melanophore hormone in warm-blooded animals. The evidence for this view is mainly of a chemical nature, since extracts prepared from the pituitary in various ways, or from the intermediate lobe alone, produce the various metabolic effects mentioned above and at the same time are rich in the melanophore hormone.

If intermedin is responsible for the diabetogenic effects, it should be possible to obtain supporting evidence by physiological methods in some cold-blooded vertebrate that depends on the pituitary for the regulation of its integumentary melanophores. A very favorable animal for such an investigation is the smooth dogfish, *Mustelus canis,* in which Orias (1932) has already demonstrated the amelioration of pancreatic diabetes by complete hypophysectomy. The physiology of the intermediate lobe of the pituitary of this animal is well understood, and its secretion can be controlled at will (cf. Abramowitz, 1939*a*). The effects of the presence or absence of intermedin in the blood on the resting blood sugar, or on the severity of experimental diabetes, could then easily be determined. Of considerable interest in this connection is the report of Slome (1936) that the blood sugar of black-adapted toads is significantly higher than

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[2] Contribution No. 246.

that of white-adapted toads, a situation which is not unfavorable to the view that intermedin is diabetogenic. However, Slome concluded that the diabetogenic hormone was produced by the anterior lobe since removal of the entire pituitary or of the anterior lobe alone decreased the severity of pancreatic diabetes. Another advantageous feature in using the dogfish is the facility of surgical treatment of the pituitary. Either the anterior or the neuro-intermediate lobe can be removed separately, and it is therefore possible to determine the relative effects of different parts of the hypophysis on carbohydrate metabolism.

The experiments to be described in this paper were undertaken to determine whether intermedin is identical with the diabetogenic hormone. The richness of intermedin in partly purified extracts possessing the ability to produce metabolic effects is suggestive but rather circumstantial evidence that such effects are due to intermedin, since many chemically similar hormones may be present in partly refined preparations. This question can be tested directly in the dogfish by experimental regulation of intermedin secretion. If the chromatic function of the pituitary can be correlated with its diabetogenic function, the probability that both effects are due to the same hormone is enhanced. On the other hand, if these two effects can be shown to occur independently, it becomes reasonably certain that they are not due to the same principle.

Materials and Methods

Pups, yearlings, and two-year-old dogfish, *Mustelus canis,* of both sexes were employed since sufficient numbers of one age group were not obtainable. However, most of the animals were yearlings. The fish were captured either by large traps or caught on hook and line, transferred to large live cars, and fed daily with generous portions of fresh squid. When a sufficient number of fish for a particular experiment had accumulated, they were placed in smaller indoor tanks, marked so that each individual could be identified, and an initial blood sugar determination was made. Further treatment will be described under separate headings in the experimental section.

Pancreatectomy in the dogfish is a simple matter and merits no description. Partial hypophysectomy is a more complicated operation, however. After immobilization of the animal by cooling in iced seawater (Parker, 1937) the fish was strapped to a V-shaped operating board, and the mouth held open by retractors. An incision about one-half inch in length was made in the oral epithelium, exposing the cartilaginous skull directly over the hypophysis. With a small scalpel, a 3 mm. incision was made in the skull parallel to and slightly posterior to

the optic chiasma. Two somewhat longer incisions were then made from the edges of the lateral incision posteriorly and parallel to the sides of the jaws. The flap thus formed was bent caudally until the anterior edge of the neuro-intermediate lobe was visible. For the removal of the anterior lobe alone, the distal part was dissected away from the neuro-intermediate lobe by passing a small curved knife through the connections between the two lobes. The tongue of the anterior lobe was then dissected off the hypothalamus and the entire lobe removed with fine forceps. For the removal of the neuro-intermediate lobe alone, the distal portion of the anterior lobe was dissected free of the neuro-intermediate lobe and deflected slightly. The large neuro-intermediate lobe was then either lifted out, usually in one piece, or removed by suction. For complete hypophysectomy, the procedure was reversed. The tongue of the anterior lobe was removed first, and then the remainder of the pituitary, after severing it from the ventral lobe. Complete hypophysectomy as used here consists of the removal of the anterior and neuro-intermediate lobes. The ventral lobe, of uncertain significance, remained embedded in the cartilage. The sacculus vasculosus was also left intact. When the operation was completed, the cartilagenous flap was allowed to settle in place thus closing the wound, and the oral epithelium sutured. About 4 to 7 minutes are required for hypophysectomy, and about 10 to 15 minutes for pancreatectomy. With assistance both operations can be performed in about 10 minutes.

Blood was obtained from the caudal artery and subsequently analyzed by the macro-precipitation method of Miller and Van Slyke (1936).

Experimental

The Effect of Background on the Resting Blood Sugar

If intermedin is the diabetogenic hormone, it might be expected that fishes subjected to a prolonged adaptation to a black background would have higher blood sugar values than those adapted to a white background, since the former state is produced by a continuous discharge of intermedin whereas the latter state results from an inhibition of the secretion of this hormone.[3] Citation of such a condition in the toad has already been made. Accordingly, dogfishes which had been previously fed for various periods, were brought into the indoor tanks, and an initial

[3] This version of the physiology of the neuro-intermediate lobe in the dogfish is, however, open to criticism (cf. Abramowitz, 1939*b*) since it is believed by some that the white-adapted state is due to the secretion of a new hypophyseal hormone. However this may turn out, it is generally agreed that during black-adaptation there is an abundance of intermedin secretion, and during white-adaptation, less or probably no circulating intermedin.

TABLE I

The effect of background on the blood sugar of starved dogfish. Blood sugar in milligrams per cent.

Initial	Days Starvation after Initial Determinations							Background	
	1	2	3	4	5	6	7		
216	198	168	127	122	117	132	116	Black	*A*
236	140	131	125	141	128	—	110		
Average 226	169	149	126	131	122	132	113		
252	138	130	113	130	98	136	97	White	
219	162	123	101	100	94	106	93		
Average 235	150	126	107	115	96	121	95		
126	130	146	112	107	101	106	124	Black	*B*
116	147	136	—	120	104	113	75		
140	—	156	136	112	126	114	114		
143	150	155	137	116	—	87	87		
Average 131	142	148	128	114	110	105	100		
102	119	108	98	104	111	102	109	White	
112	145	148	148	118	124	110	124		
164	150	149	150	132	134	107	104		
150	149	155	140	117	121	124	135		
Average 132	140	140	134	118	122	111	118		
156	—	135	121	—	103	—	—	Intermediate	
139	—	125	122	—	137	—	—		
121	—	134	132	—	116	—	—		
137	—	125	161	—	120	—	—		
Average 138		129	134		119				
Grand Average 158±11.3	148±5.5	139±3.8	128±4.3	118±3.4	116±3.3	112±4.0	107±4.7		
No. of Animals (16)	(11)	(16)	(15)	(12)	(15)	(11)	(12)		

blood sugar value obtained. The fishes were then placed on white, black, and intermediate backgrounds, starved[4] for the duration of the experiment, and their blood sugar level followed daily.

As the data in Table I clearly show, there is no effect of background on the resting blood sugar level of the dogfish. In one series (Column A, Table I) the black-adapted fish showed higher values than the white-adapted fish, but in a second series (Column B) the order was reversed. There are, however, several significant observations to be pointed out. The initial values in Table I as well as in the following tables show considerable variation. This is mostly due to the extent of previous feeding, for fish that were freshly obtained may show low or high values, whereas animals which were fed for several weeks always show high initial values. This is clearly illustrated in the data (Table I) where the initial readings for well-fed animals (Column A) are nearly twice those of meagerly fed animals (Column B). However, the blood sugar values fall gradually during starvation and reach a constant level after the third day. The level reached is quite independent of the magnitude of the initial values.

Since there was no effect of background on blood sugar level, all of the individual determinations were averaged and the result expressed as grand averages at the foot of Table I. These averages, therefore, represent blood sugar level as a function of the time of starvation and serve as standard values for comparison with results obtained in other experimental series. It can be seen that after the second day of starvation the standard deviation of the averages assumes a low constant value, while the variation of the initial determinations is considerable, as seen from the large standard deviation. Consequently, the results for animals on which operations were performed cannot be calculated as percentages of the initial blood sugar values before operation because the initial values are not constant. The only valid comparisons are those made in relation to the standard values on the same day of starvation.

The Effect of Hypophysectomy

Orias (1932) concluded that complete hypophysectomy did not affect the blood sugar of the dogfish, since the average value for 8 fish on the second day following hypophysectomy was no different from that previous to the operation. Orias' observations are undoubtedly correct inasmuch as our data (Table II) likewise show no difference between the hypophysectomized and control groups (Table I) on the second day of starvation. However, removal of the pituitary leads to a marked hypo-

[4] In all of the experiments, the animals were starved throughout the course of an experiment.

glycemia (89–88 mg. per cent) at the fourth day of starvation. There is considerable variation, however.

The effect of partial hypophysectomy was determined by removal of only the anterior lobe in 14 animals, and of only the neuro-intermediate lobe in 11 animals. Both sets of animals were followed for a week. The effect of the removal of the anterior lobe (Table III) is very similar to that of complete hypophysectomy. The level reached (96–94 mg. per cent) is not as low as that following complete hypophysectomy, but there is less variation. Removal of the neuro-intermediate lobe (Table IV), however, does not lead to hypoglycemia, and the average values

TABLE II

The effect of the removal of the pituitary on the blood sugar of starved dogfish. Blood sugar in milligrams per cent.

Initial	Days starvation following operation						
	1	2	3	4	6	9	11
108	—	101	—	72	53		
190	—	99	—	97	89	90	82
216	—	201	—	161	158	129	121
201	—	115	—	98	110	88	
290	—	78	—	63	82		
117	—	270	—	126			
228	—	190	—				
151	102	87	83	70	93		
132	131	117	109	114	75		
177	—	112	—	101	103		
121	—	104	—	35			
112	—	—	—	42	30		
Ave. 170	—	134±17.2	—	89±10.8	88±11.3		
No. of Animals	—	(11)	—	(11)	(9)		

for this series are remarkably close to those of the control series (Table I). The results of the three series of operations as compared with the control series are summarized in Table V.

It can be concluded that the removal of the anterior lobe produces the same effect as that seen after complete hypophysectomy and that the ablation of the neuro-intermediate lobe has no effect on blood sugar. Furthermore, the hypoglycemia, which follows the removal of the anterior lobe, occurs in spite of a continuous secretion of intermedin (Abramowitz, 1939*b*), and on the other hand, hypoglycemia does not occur after ablation of the neuro-intermediate lobe which deprives the dogfish entirely of intermedin.

Table III

The effect of the removal of the anterior lobe of the pituitary on the blood sugar of starved dogfish. Blood sugar in milligrams per cent.

Initial	Days starvation following operation				
	1	2	3	4	6
124	—	106	—	126	85
168					
118	—	107	—	89	89
240	—	116	—	105	110
137	—	165	—	88	—
111	—	114	—	110	121
155	—	103	—	90	115
260					
130	—	88	—	64	32
163	168	112	131	117	113
132	132	113	100	83	
126	—	122	—	93	110
112	—	118	—	94	71
107	—	118	—	90	90
Ave. 148	—	115±5	—	96±4.5	94±8
No. of Animals	—	(12)	—	(12)	(10)

Table IV

The effect of the removal of the intermediate lobe of the pituitary on the blood sugar of starved dogfish. Blood sugar in milligrams per cent.

Initial	Days starvation following operation					
	1	2	3	4	5	7
117	—	193				
154	—	166	110	143		
125	—	109	107	98	115	107
161	—	164	128	117	110	187
122	—	163	111	104	124	141
128	—	130	109	109	—	
134	186	111	113	106	112	
102	114	113	122	110	144	
128	—	124	112	—	114	
132	—	116	89	—	95	
130	—	145	114	—	119	
Ave. 130		139±8.2	112±3.0	112±5.2	117±4.6	
No. of Animals		(11)	(10)	(7)	(8)	

The experiments just described furnish good evidence that the presence or absence of intermedin is without effect on the resting blood sugar level. The most crucial test of the identity of the diabetogenic and chromatophorotropic hormones of the pituitary, however, is one performed on the depancreatized animal. If the continued presence of intermedin in the body is not accompanied by an aggravation of experimental diabetes, and if its complete absence is not accompanied by an amelioration of diabetes, there can be little doubt that intermedin is not the diabetogenic factor. Therefore, the effects of background and of partial hypophysectomy on the blood sugar level of depancreatized dogfish were determined. The results of this series of experiments follow.

TABLE V

Summary table showing the effects of partial and complete hypophysectomy on the resting blood sugar level of starved dogfish.

Operation	Initial value	Blood Sugar in Milligrams Per Cent			
		Days following operation			
		2	4	5	6
Controls	158	139	118		112
Complete hypophysectomy	170	134	89		88
Anterior lobe removed	148	115	96		94
Intermediate lobe removed	130	139	112	117	

Pancreatic Diabetes

Twenty-five fish, fed for various periods of time, were depancreatized after an initial determination had been obtained. Nine were placed in white and sixteen in black tanks. Both sets were starved and the blood sugar values determined daily. The results (Table VI) show that the severity of diabetes is not influenced by the relative amounts of circulating intermedin. In some instances, the black-adapted group showed a slightly more intense diabetes, and in other instances, the reverse was true. All the data were therefore averaged, and the values, given at the foot of Table VI, indicate merely the blood sugar level of depancreatized animals on various days of starvation. The depancreatized animals show values roughly three times those of the control series.

An interesting point with regard to the effects of pancreatectomy in the dogfish is the fact that the severity of the resulting diabetes is inde-

pendent of the blood sugar level prior to the operation. Initial values around 200 mg. per cent indicate fish which had been fed for several weeks prior to operation, yet the resulting diabetes following pancreatectomy is approximately the same as that of poorly fed animals. For example, the initial value of 98 mg. per cent (poorly fed fish) rose to 422, 473 and 500 mg. per cent, a level which is as high as that found in the well-fed individuals. This illustrates again that the results cannot

TABLE VI

Pancreatic diabetes in dogfish starved after initial readings. Blood sugar in milligrams per cent.

Initial	Days Starvation after Pancreatectomy									
	1	2	3	4	5	6	7	8		Background
193	235	208	255	195						
175	275	210	270	242	191	175				
212	319	291	346	442	508	514	583	496	410	
156	272	172	175	242						
215	371	381	512	584						
269	377	294								White
231	282	245	226							
284	380	342	593							
232	452	330	392	393						
Average 213	320	275	347	350						
149	—	—	250							
198	—	—	216							
209	—	—	150							
234	391	—	392							
217	356	388	—							
98	422	473	500	445						
134	356	418								
135	562	258								
125	—	—	130							Black
236	—	—	432							
197	—	—	280							
146	—	—	400							
160	—	—	350							
198	—	—	526							
Average 174	417	384	330							
[120	94	44]								
94	29	30]								
Grand Average 191	361±22	308±24.2	337±30	363±50						
No. of Animals (23)	(14)	(13)	(19)	(7)						

be calculated in terms of the initial values. Secondly, there appears to be no uniformity among the individual fish during the course of their diabetic condition. Some of the animals become progressively more diabetic, some maintain a constant level, and some tend to show decreasing hyperglycemias after the first twenty-four hours.

Inspection of the values listed in Table VI reveals a considerable individual variation. This is somewhat contrary to the results obtained by Orias whose nine depancreatized animals had values between 350 and 431 mg. per cent with an average of 402 mg. per cent at 48 hours fol-

lowing operation. Our results can be arbitrarily classified into four main groups: (1) severe diabetes, (2) mild diabetes, (3) no diabetes, and (4) hypoglycemia. The first group represents values above 300 mg.

TABLE VII

Effects of complete and partial hypophysectomy on pancreatic diabetes. Blood sugar in milligrams per cent.

Pancreas + Pituitary removed	Pancreas + Anterior lobe removed	Pancreas + Intermediate lobe removed
100	[96	[96
110	79	28]
117	43	
133	88]	
176		
173		175
134		182
	159	120
	146	126
	121	196
368	120	164
350	114	
370	143	
311	119	
425		800+
437		391
		385
	335	335
	433	484
212	382	548
233	333	682
289	462	307
213		478
292		319
282		445
293	285	689
273	284	392
204	228	
247	206	
294	202	
212	298	284
224	233	297
	219	254
		226
		211
Ave. 249±18	241±23	354±36
No. of Animals (26)	(20)	(24)

per cent, the second between 200 and 300 mg. per cent, the third between 100 and 200 mg. per cent, and the fourth, values below 100 mg. per cent which is below that of a normal animal. Such a classification is, of

course, quite rough, but it serves to bring out a significant comparison with results obtained in the next section where both pancreas and pituitary were removed. The percentages of the animals falling into the various groups are shown in Table VIII. Most of the depancreatized animals (56 per cent) become severely diabetic, 24–28 per cent are only mildly diabetic, and 8–12 per cent do not develop hyperglycemic levels at all. That a small percentage of animals does not become diabetic seems to be a constant factor, for a similar percentage has been found in all cases involving removal of the pancreas. Two of the twenty-five animals, or 8 per cent, developed hypoglycemia. These two animals were not included in the calculations of the averages in Table VI, since they are obviously anomalous. This, too, appears to be a constant factor for it has recurred in the other series of operations in about the same percentage of cases.

TABLE VIII

Summary table showing distribution of results among arbitrary classes of diabetes. Figures indicate percentage of the animals comprising the various types.

Operation	Hypo-glycemia	No Diabetes	Mild Diabetes	Severe Diabetes
Range of blood sugar, Mg. %	<100	100–200	200–300	>300
Pancreas alone removed	8%	8–12%	24–28%	56%
Pituitary + pancreas removed	0–3.85%	23.2–26.8%	50%	23.2%
Anterior lobe + pancreas removed	16.6%	29.4%	33.6%	20.4%
Intermediate lobe + pancreas removed	7.7%	23.1%	19.2%	50.0%

A few animals were followed immediately after pancreatectomy to determine how soon hyperglycemia appeared. The blood sugar rose shortly after operation and reached peak levels within nine to twelve hours.

The Effect of Complete and Partial Hypophysectomy on Experimental Diabetes

Seventy-six animals were depancreatized and hypophysectomized simultaneously. In 26 animals, the pancreas and the whole pituitary were removed; in 26 the pancreas and only the neuro-intermediate lobe were removed; and in 24 the pancreas and only the anterior lobe were removed. Blood sugar analyses were made daily, but due to high mortality, only the determinations on the first day following operation were listed in Table VII. An individual variation in the severity of diabetes, such as that described for pancreatectomy, was encountered, and the per-

centage of cases showing the various types of diabetes is given, for each of the 3 series of operations, in Table VIII.

Complete hypophysectomy tends to reduce the severity of experimental diabetes. As shown in Table VII, the average blood sugar level is 249 mg. per cent, which is somewhat lower than the average of 9 animals (281 mg. per cent) found by Orias. The greatest number of animals (50 per cent) show a mild type of diabetes, and 23 per cent show either no diabetes or a severe diabetes. None of the animals was hypoglycemic at the first day, but 2 animals showing the lowest readings (100 and 110 mg. per cent) became hypoglycemic on the third and fourth days.

The average value of 20 animals from which both the anterior lobe and the pancreas were removed was 241 mg. per cent, which is practically the same level as that found in completely hypophysectomized-depancreatized animals. Sixteen per cent showed hypoglycemia and was not included in the calculation of the average for this group. Twenty-nine per cent showed no diabetes and 20 per cent showed a severe type. On the whole, the results of this group are similar to those obtained when the pancreas and the entire pituitary were removed.

The results obtained when only the neuro-intermediate lobe and pancreas were removed are quite different from those of the other two groups of animals in this series of operations but similar to those obtained when only the pancreas was removed. The average value of this group (excluding the 8 per cent showing hypoglycemic levels) was 354 mg. per cent. Most of the animals (50 per cent) showed severe diabetes, 19 per cent showed mild diabetes, and 23 per cent were not diabetic. One of the animals showed an extremely high level of 800 mg. per cent, which is probably an anomalous value. Excluding this value, the average of this group would be somewhat lower (334 mg. per cent), which is still a severely diabetic level.

Examination of the summary table (Table VIII) leaves little doubt that complete hypophysectomy alleviates pancreatic diabetes. Anterior lobe removal accomplishes the same result but the removal of the neuro-intermediate lobe has little effect on the severity of experimental diabetes. These results are consistent with those of the previous experimental series, and lead to the conclusion that the diabetogenic hormone in the dogfish is produced by the anterior lobe of the pituitary, and that this hormone is not identical with intermedin.

Summary

The resting blood sugar level and the severity of pancreatic diabetes are not influenced by fluctuations in intermedin secretion in the dogfish.

Complete hypophysectomy is followed by the appearance of hypoglycemia on the fourth day following the operation, a response which is also produced by the removal of the anterior lobe alone. Removal of the neuro-intermediate lobe does not affect the resting blood sugar level. Complete hypophysectomy ameliorates the severity of pancreatic diabetes, as does the removal of the anterior lobe alone. The removal of the neuro-intermediate lobe alone does not influence pancreatic diabetes. These results show that intermedin and the diabetogenic hormones of the pituitary of the dogfish are not identical.

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Contribution No. 247

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THE EXPERIMENTAL PRODUCTION OF MELANIN PIGMENT ON THE LOWER SURFACE OF SUMMER FLOUNDERS (PARALICHTHYS DENTATUS)[1, 2]

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Communicated January 25, 1940

Differences in the degree of pigmentation on the upper and lower surfaces of animals have for centuries attracted man's interest. Such differential pigmentation, although perhaps most markedly exemplified in the lower vertebrates (fishes and amphibians), is seen also to a lesser extent in all the other vertebrate classes and even in many invertebrates.

Flounders provide an excellent example of differential pigmentation as they have entirely unpigmented lower sides but densely pigmented upper surfaces. They are doubly interesting because as larvae they display bilateral pigmentation which disappears on one side coincident with the migration of one eye and the secondary or adult orientation of the fish in a plane at right angles to the original (Agassiz, 1878). Naturally enough, Cunningham (1891, 1893, 1895) associated light with the presence of pigmentation and, on this basis, illuminated larval flatfishes ventrally to see if the bilaterally pigmented pattern would be retained even after the metamorphosis of the fish and the secondary orientation of the body with one flat surface against the substrate. Although he failed to retain the original bilateral pattern, it was found in a fair percentage of cases that after several months of ventral illumination some pigment did develop on the normally unpigmented lower side. However, Agassiz (1878) reported no development of ventral[3] pigment in flounder larvae which were exposed to light ventrally for the express purpose of arresting the migration of the eye in metamorphosis.

[1] This work was aided in part by a Bache Fund grant administered by Professor G. H. Parker.

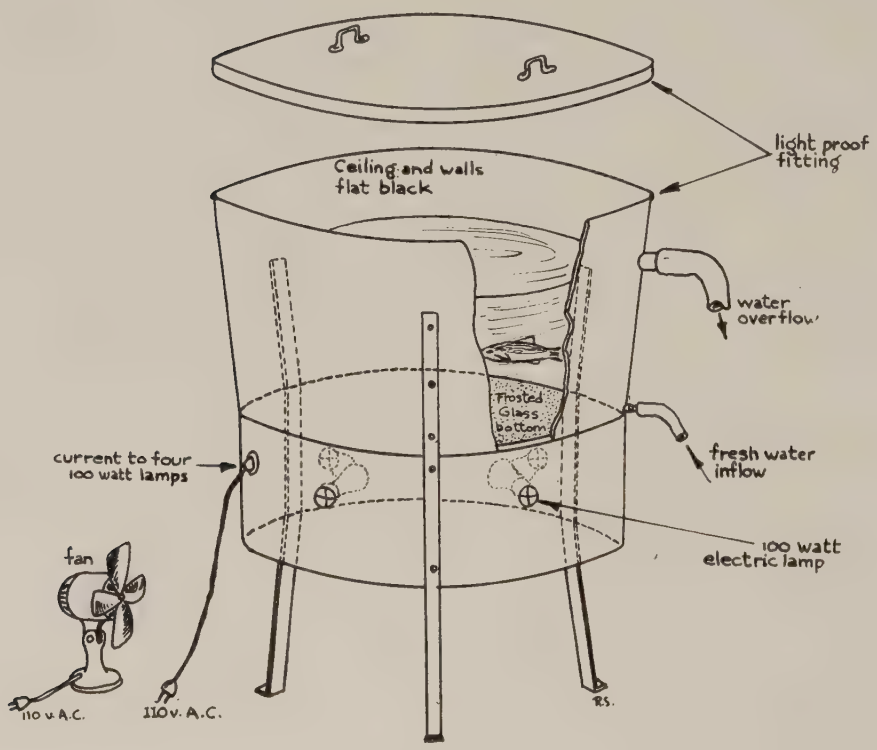
[2] Contribution No. 247 of the Woods Hole Oceanographic Institution whose research facilities were generously provided for this investigation.

[3] The term "ventral" will be used in this paper to indicate the lower surface of a naturally oriented fish.

This paper presents descriptive data on preliminary experiments designed to show the relationship between directed continuous illumination, vision and the production of melanin pigment.

Materials and Methods.—The experimental flatfishes, summer flounders (*Paralichthys dentatus*) 11 to 17 inches long, were taken by otter trawl from Woods Hole waters. Live cars of neutral shade were anchored in the harbor for storing stock animals but most of the fishes used were freshly

FIG. A, EXPERIMENTAL SETUP PROVIDING VENTRAL ILLUMINATION



netted. Ventral illumination was provided by an apparatus similar to that shown in Fig. *A*. The temperature of the running sea water averaged 19°C. throughout these experiments. Some of the fishes were blinded by complete optic enucleation and in others both optic nerves were cut. Large experimental tanks painted black or white inside and illuminated continuously from above were used for extreme (black or white) back-

ground adaptation. Numerous controls were kept for each experimental situation.

Experiments and Observations:

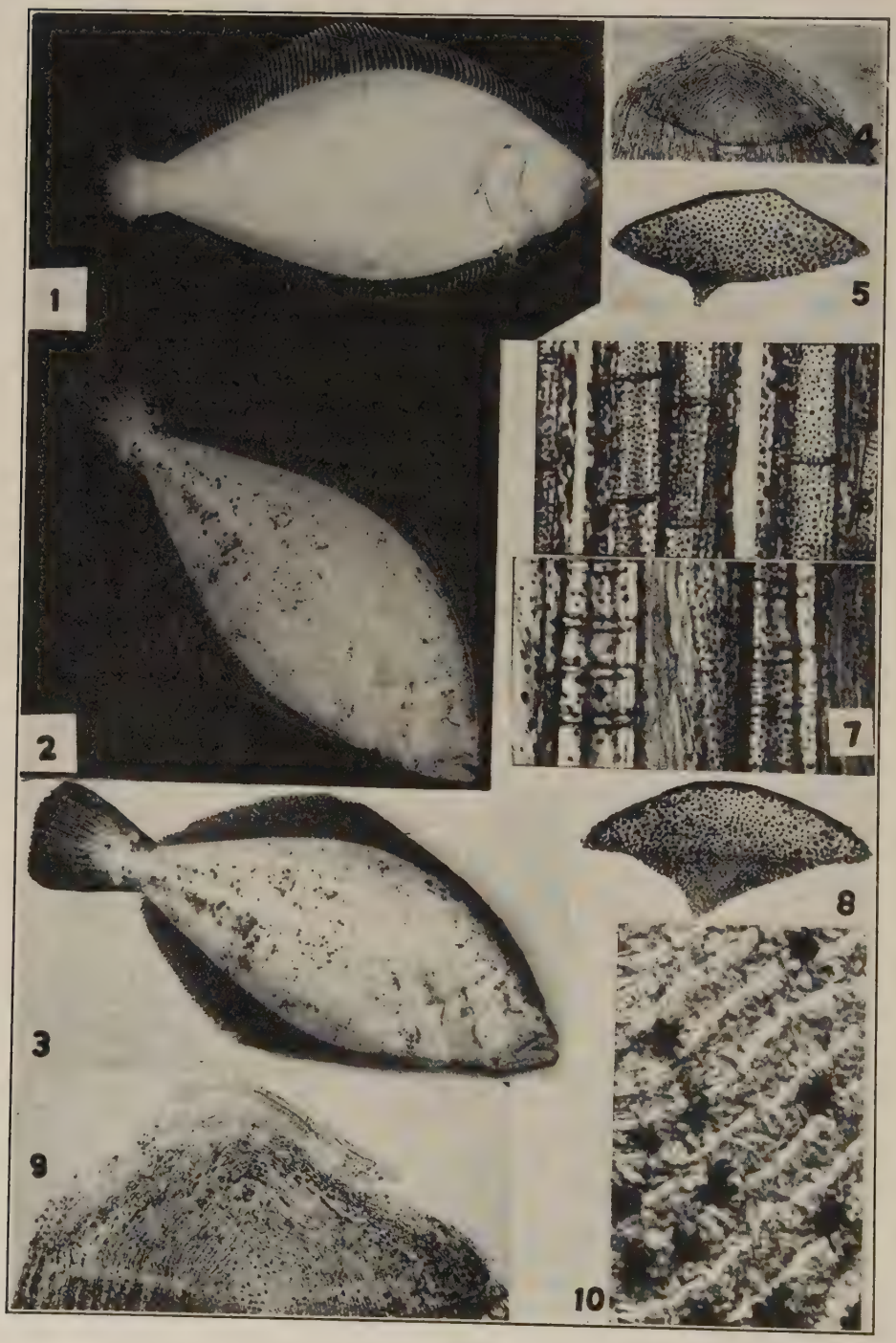
1. *Unoperated Flounders with Lower Surface Illuminated.*—Eight freshly caught summer flounders were, on different occasions, placed in the apparatus providing a diffuse direct illumination of the lower side for periods ranging from seven to 51 days. Pigment developed to some extent on the normally pale surface (Fig. 1) of all of these fishes. In one flounder the first pigment was apparent after seven days but only after 15 to 25 days of ventral illumination was a melanin development obvious in most of the animals. After these initial stages the macroscopic increase in melanin was more rapid. A growth comparable to that in figures 2 and 3 was attained in about seven weeks. The general body shade (upper surface) of animals kept in the apparatus (black side walls and ceiling) was definitely darker than intermediate but yet not fully black-adapted. They were more nearly dark brown than black. Paler contrasty spots were frequently observed.

2. *Blinded Black Flounders Illuminated on Lower Surface.*—Five black-adapted flounders were blinded and placed in the apparatus providing ventral illumination. All of these fishes developed ventral pigment which first became apparent in 12 to 14 days and became pronounced in 45 days.

3. *Unoperated Flounders on Black Background Illuminated from Above.*—Another set of 12 unoperated fishes was placed in an experimental tank illuminated from above. The floor and side walls were flat black and the light source was of the same intensity as in the previous experiments. The animals became black-adapted in a few hours (Osborn '39*a*), finally reaching a fully black shade which persisted throughout the experiment. Typical white excitement spots could be elicited at any time upon application of the appropriate stimulus (Osborn '39*a*). The fishes remained in this situation for periods ranging from 15 to 70 days but none developed ventral pigment.

4. *Blinded Black Flounders on Black Background Illuminated from Above.*—Experiment 3 was repeated with ten flounders but this time the animals were totally blinded as soon as they were fully black-adapted. Such fishes were maintained under these conditions as long as 56 days but ventral pigment did not develop.

5. *Blinded Black Flounders on White Background Illuminated from Above.*—Summer flounders, 14 in all, were totally blinded following black-adaptation and were then transferred to white experimental tanks continuously illuminated from above. Flounders thus prepared remain maximally dark even on the white background (Osborn '39*a*). The light source was of the same intensity as employed above but the resulting illumination much brighter due to the high incidence of reflection from the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white floor and walls of the tank. Under these conditions, some evidence of developing ventral pigment appeared as soon as 15 days but the process was very slow and only a small amount developed in 60 to 70 days. Longer periods of treatment would undoubtedly result in increased pigmentation. However, the unmistakable amounts of ventral pigment developing in every fish suggest that vision is not essential to this process. On the contrary, normal unoperated control fishes placed under similar conditions at the same time failed to develop any ventral pigment and, of course, became typically white-adapted on the upper surface (Osborn '39*a*). Furthermore, it has been shown in fundulus and catfish that prolonged white-adaptation actually results in melanophore degeneration and an absolute decrease in the melanin of the skin (Odiorne '37).

6. *Blinded White Flounders on White Background Illuminated from Above.*—Nine fishes were completely white-adapted (seven days) and then totally blinded and replaced in illuminated white tanks under conditions identical with those of experiment No. 5. Summer flounders so prepared do not darken quickly and maximally as do many fishes but rather darken very slowly to an intermediate shade (Osborn '39*a* and *b*). Of nine such animals, six failed to develop appreciable amounts of ventral pigment in 40

PLATE 1

EXPLANATION OF FIGURES

Figure 1. Lower unpigmented surface of a normal summer flounder which was removed from nature and photographed immediately. The upper surface was in the dark phase. $^1/_5$ natural size.

Figure 2. Lower surface of a summer flounder which had been illuminated ventrally for seven weeks in the apparatus in figure A. Note that considerable pigment has developed. $^1/_5$ natural size.

Figure 3. Same as figure 2 but on white background to show the developed pigment in better contrast.

Figure 4. Photomicrograph of the exposed surface of a typical scale plucked from the lower surface of a normal untreated fish. Note that no trace of pigmentation is apparent. × 25.

Figure 5. Scale plucked from upper normally pigmented surface of a summer flounder. The scale surface is quite fully covered by melanophores. × 25.

Figure 6. Portion of the pectoral fin taken from the pigmented side of a control fish. It is highly pigmented. × 25.

Figure 7. Portion of the pectoral fin removed from the lower normally unpigmented surface of a fish which received ventral illumination for 6 weeks. This treatment has produced marked pigmentation. × 25.

Figure 8. A scale plucked from the lower surface of a fish illuminated ventrally 7 weeks. Note that it is pigmented as fully as is the dorsal scale in figure 5. × 25.

Figure 9. A scale from the lower surface of a fish illuminated ventrally for 3 weeks. Macroscopically only initial traces of pigmentation could be detected. Note that the melanophores are sparsely distributed. × 25.

Figure 10. An area of the scale in figure 9 showing the details of the newly developed melanophores. × 140.

to 50 days. The other three fishes exhibited early stages of melanophore development on a few scales. This experiment must be repeated on more animals and be allowed to run three or four months.

7. *Blinded Flounders on Illuminated Backgrounds.*—Seven summer flounders were totally blinded as soon as they were taken from nature. They were an intermediate greenish brown at the time. After blinding, they darkened slightly to a very homogeneous deep chocolate-brown and were placed in an illuminated *white* experimental tank as in the previous experiments. These fishes developed appreciable ventral pigment in 38 days and definitely more in 50 to 60 days. Two other fishes received similar treatment in all details but were placed in an illuminated *black* experimental tank. Pigment did not develop on the lower surface of either of these fishes in 52 days.

Discussion.—Perhaps Agassiz failed to get pigmentation because his light source (daylight) was not directed onto the lower surface of the fishes. They were simply placed in glass-bottomed dishes near the window. Since daylight varies in intensity with time of day and the weather, it would necessarily take two or three times as long for positive results as would continuous artificial illumination of constant high intensity. Agassiz, who was primarily interested in the migration of the eye in metamorphosis, probably did not continue his experiments long enough to grow pigment.

Cunningham designed his experiments for pigment studies, continued them for periods of from several months to over a year and reflected daylight by mirrors directly onto the lower surfaces of his fishes.

The confirmatory results presented here were obtained in relatively shorter periods probably because the light was of higher intensity and directed continuously onto the animals. These flounders were also larger and older than those used by previous investigators.

The artificially produced pigment is melanin in melanophores (Figs. 7, 8, 9 and 10) which appear to be normal morphologically and physiologically. When ventral scales bearing these melanophores are pláced in adrenalin a typical concentration of the pigment granules occurs. Furthermore, when the scale is plucked and the nervous connections severed, the melanophores typically exhibit maximal expansion.

The source of these new melanophores is an unsettled question. Two possibilities are indicated: either they differentiate from some other cell already at the site or they migrate in from other areas. In the latter case they might migrate as typical melanophores or as cells capable of becoming melanophores. Experiments designed to provide more information on these points are now in progress. Thus far, no evidence for the migration of melanophores to the unpigmented area has been obtained. Cunningham, failing to find evidence to the contrary, believed that the pigment cells developed *in situ*.

Summary.—An apparatus providing continuous artificial illumination of constant intensity directed to the lower surface of flounders is pictured. Pigmentation was developed on the lower normally unpigmented surface in a high percentage of summer flounders in the following experimental situations: (1) Unoperated fishes in black tanks illuminated from below. (2) Blinded dark fishes in black tanks illuminated from below or in white tanks illuminated from above.

The observation that flounders blinded in the dark phase developed ventral pigment as readily as unoperated ones indicates that the eyes are not essential to this reaction.

Light is a necessary factor in the production of ventral pigment.

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Contribution No. 248

CORRIGENDA

PAGE 190: For 1,450 meters depth, read 1,440 fathoms depth.
For 21° 38′ N., 79° 56′ 30″ W., 690-700 fathoms
read 21° 38′ N., 80° 12′ 08″ W., 1,440 fathoms.
Transfer the entire section about *Zygothuria* to page 193.

,, 192: Delete Stations 3,366 and 3,459 and read:
Station 3,359 20° 38′ N., 74° 32′ W., 1,000 fathoms.

,, 200: Transfer stations 3,367 and 3,369 to top of page.

,, 217: In the key to Molpadiidae:
for *Ceraplectana,* read *Molpadia*
for *Molpadia,* read *Ceraplectana.*

,, 237: Under Station 3,355, add *Benthodytes typica* Théel.

,, 239: Under Station 3,459, delete *Mesothuria maroccana* Deichmann.
Under Station 3,475, add *Sphaerothuria asperrima* (Théel).

REPORT ON THE HOLOTHURIANS, COLLECTED BY THE HARVARD-HAVANA EXPEDITIONS 1938 AND 1939, WITH A REVISION OF THE MOLPADONIA OF THE ATLANTIC OCEAN*

BY ELISABETH DEICHMANN

Museum of Comparative Zoölogy.

Very little dredging has been undertaken in the West Indian seas since the days of Alexander Agassiz and our knowledge about the deepwater holothurians rests almost completely on the material secured by the "Blake" and "Albatross". A few hauls were made by the "Fish Hawk" in the waters around Porto Rico in 1898 and in later years the Vanderbilt and Bingham expeditions have supplemented our knowledge about certain deep water invertebrates and their distribution.

The "Atlantis" cruises during the spring of 1938 and 1939, in the waters around Cuba, partly in the classical collecting grounds of the "Blake", have yielded an enormous amount of material of fishes and invertebrates and among the latter also a large number of holothurians.

As it was to be expected not many species are new. The group itself is small and the majority of the forms from deeper water are widespread and have therefore previously been described from other parts of the Atlantic Ocean. Three species are new (one was, however, previously listed under a wrong name, by Théel and later erroneously described as the juvenile stage of another species by Deichmann in 1930); three species are reported for the first time from the western part of the Atlantic Ocean while other records represent the first in which the species have been taken in numbers. Most valuable is the collection of Molpadonia and since that group was rather briefly

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treated in 1930 (the existing material in the U. S. N. M. having been exhaustively treated by H. L. Clark in 1908), the Atlantic forms of that order have now been revised and the recent literature critically discussed.

Besides the material from the Harvard-Havana expeditions, a few species are included which were secured by same of the "Atlantis" cruises from off New England, Georges Bank, etc. Also a few species from other sources (in the M. C. Z.) have been included to complete the account.

LIST OF SPECIES

Order Aspidochirota.
- Family Synallactidae.
  - Synallactes Ludwig.
    - *Synallactes crucifera* Perrier.
  - Bathyplotes Oestergren.
    - *Bathyplotes bigelowi* spec. nov.
    - *Bathyplotes pourtalesi* (Théel).
  - Amphigymnas Walsh.
    - *Amphigymnas bahamensis* Deichmann.
  - Pseudostichopus Théel.
    - *Pseudostichopus occultatus* v. Marenzeller.
  - Mesothuria Ludwig.
    - *Mesothuria gargantua* Deichmann.
    - *Mesothuria maroccana* Perrier.
    - *Mesothuria verrilli* (Théel).
  - Zygothuria Perrier.
    - *Zygothuria lactea* (Théel).
- Family Stichopodidae.
  - Stichopus Brandt.
    - *Stichopus regalis* (Cuvier).
    - *Stichopus badionotus* Selenka.
- Family Holothuriidae.
  - Holothuria Linnaeus.
    - *Holothuria mexicana* Ludwig.
    - *Holothuria lentiginosa* v. Marenzeller.
    - *Holothuria occidentalis* Ludwig.

Order Elasipoda.
- Family Deimatidae.
  - Deima Théel.
    - *Deima blakei* Théeel.
  - Orphnurgus Théel.
- Family Psychropotidae.

Benthodytes Théel.
Benthodytes typica Théel.
Benthodytes lingua Perrier.
Euphronides Théel.
Euphronides kerhervei Perrier.

Order Dendrochirota.
Family Cucumariidae.
Sphaerothuria Ludwig.
Sphaerothuria asperrima (Théel).
Sphaerothuria talismani (E. Perrier).
Family Psolidae.
Psolus Oken.
Psolus pourtalesi Théel.

Order Molpadonia.
[Family Gephyrothuriidae fam. nov.
Gephyrothuria Koehler & Vaney.
**Gephyrothuria glauca* (H. L. Clark)]
Family Mopadiidae.
**Molpadia agassizi* (Théel).
Molpadia barbouri spec. nov.
Molpadia blakei (Théel).
Molpadia cubana spec. nov.
Molpadia musculus (Risso).
**Molpadia oolitica* (Pourtalès).
Family Caudinidae.
Caudina.
Caudina arenata Gould.
Paracaudina Heding.
Paracaudina obesacauda H. L. Clark.
Hedingia Deichmann.
Hedingia albicans (Théel).
[Family Eupyrgidae.
Eupyrgus Lütken.
**Eupyrgus scaber* Lütken]
Order Apoda.
Family Synaptidae.
Euapta Oestergren.
Euapta lappa (J. Müller).
Protankyra Oestergren.
Protankyra brychia (Verrill).
Family Chiridotidae.
Chiridota Eschscholtz.
Chiridota abyssorum v. Marenzeller.
**Chiridota ferruginea* (Verril).

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* Species marked with an asterisk were not secured by the Harvard-Havana cruises. In brackets are placed families genera and species which have been only briefly discussed.

ORDER I — ASPIDOCHIROTA

FAMILY SYNALLACTIDAE

Genus SYNALLACTES Ludwig

SYNALLACTES CRUCIFERA Perrier
(Plate 31, figs. 5-6)

Synallactes crucifera Perrier, 1898, p. 1,665; 1901, p. 339, pl. 12, figs. 5-6, pl. 17, figs. 21-35. Deichmann, 1930, p. 106 (*passim*).

Diagnosis. — Small form (6-8 cm.); mouth ventrally placed; anus subdorsal. Ventral side with cylindrical tube feet in two lateral bands and in a scattered band along the midventral ambulacrum. Dorsal side with conical papillae in several longitudinal rows, those nearest the midline usually with whip-like tips.

Spicules cross-shaped bodies (0.077-0126 mm.) with external spire often spinous, occasionally with a terminal slit-like perforation but otherwise solid; arms of cross with one or two perforations in the ends. Feet with large end plate and branching or perforated rods, straight or curved; papillae with an irregular mass of curved rods but apparently no end plate. Color in alcohol white.

Type. — Paris.

Type locality. — Off Morocco, 2,212 meters depth.

Distribution. — Known from the type locality and now reported from off Cuba.

Depth. — From between 1,200-1,300 fathoms.

Specimens examined. — The following material from the "Atlantis" cruises.

Station 2973 21° 09′ N., 85° 04′ W., 1,280 fathoms. 1 fragment.

Remarks. — The fragment measures about 6 cm. in length and consists mostly of strips of skin; the inner organs are completely lacking. The spicules agree well with those described and figured by Perrier.

Genus BATHYPLOTES Oestergren

BATHYPLOTES POURTALESI (Théel)
(Plate 31, figs. 3-4)

Stichopus pourtalesi Théel, 1886 a, p. 4.

Bathyplotes pourtalesi Deichmann, 1930, p. 102, pl. 9, figs. 3-7, (list of references).

Diagnosis. — Large form (20 cm.); a typical *Bathyplotes* but with vaulted dorsal side with large papillae and on the ventrum numerous large "fungiform" papillae.

Spicules tables with cross-shaped disk with slender arms with few perforation in the ends and a tapering spire composed of four rods, usually smooth, and with few cross-beams. Color in alcohol white.

Type. — M. C. Z.

Type locality. — Off St. Kitts, B. W. I.

Distribution. — Widespread in the West Indian seas, also reported from the eastern Atlantic (as *B. bipartius* Hérouard).

Depth. — 202-838 fathoms.

Specimens examined. — The following material from the "Atlantis" cruises.

Station	3366	20° 46′ N., 74° 59′ W.,	625 fathoms.	2 fragments.
„	3370	20° 47′ N., 75° 11′ W.,	450 „	2 „

Bathyplotes bigelowi spec. nov.

(Plate 31, figs 1-2)

Diagnosis. — Large form (up to 25 cm.) with strongly flattened body and a continuous lateral brim of papillae interrupted only at the posterior end. Mouth ventral with 20 tentacles surrounded by a strong sphincter; anus terminal or subventral. Ventral side with cylindrical tube feet scattered without order, most numerous on the posterior part of the ventrum; a varying number of small "fungiform" papillae are present, forming two longitudinal rows. Dorsal side with two median rows of papillae, often completely retracted, and besides a few smaller papillae irregularly distributed. Skin rough to the touch on account of the large number of spicules.

Spicules a crowded layer of large tables with delicate lace-like disks with four large central holes and several smaller marginal holes; spire tall with four rods, several cross-beams and spines on the sides. Ventral tube feet with small end plate and curved supporting rods. Dorsal papillae lacking end plate. Color in alcohol white or grey, in some individuals finely dotted with brownish pigment.

Type. — M. C. Z.

Type locality. — Near Bahía de Cochinos, Sta. Clara province (Station 2323).

Distribution. — The waters around Cuba.

Depth. — From 220-320 fathoms.

Specimens examined. — The type and the following specimens, all from the "Atlantis" cruises around Cuba.

Station					Fathoms	
2963E	22° 07′	N.,	81° 08′	W.,	220-235	Fragments
2987	**23° 22′**	**N.,**	**79° 53′**	**W.,**	**280-300**	**1 good, several fragments**
2323	22° 00′	N.,	81° 09′ 30″	W.,	290-320	Type
3432	23° 05′	N.,	79° 29′	W.,	250	1 poorly preserved
3434	23° 10′	N.,	79° 35′	W.,	260	1 good, several fragments
3436	23° 05′	N.,	79° 28′	W.,	255	Fragments
3483	23° 12′ 30″	N.,	81° 22′	W.,	300	„

Remarks. — The type measures 22 cm. in length; one of the other, less perfect specimen reaches however, a length of 25 cm. The species resembles somewhat the type species, *B. natans* (Sars), which also occurs in the West Indians seas. It is, however, more flattened with a narrow body cavity and a wide marginal brim which is interrupted at the hind end; furthermore the anus is terminal or subventral, often placed in an indistinct furrow. The inner anatomy is typical; the calcareous ring is low with broad radials which are deeply incised posteriorly. Traces of tentacle ampullae are present as indistinct lobes. A single ventral Polian vesicle is present in the type and a delicate stone canal, embedded in the dorsal mesentery, its head being attached to the dorsal wall of the body cavity. The mud-filled intestine runs straigth backward, almost reaching the cloaca, bends forward for a short distance and then runs backward; the third mesentery attaches to the right ventral interambulacrum. The respiratory trees have short lateral branches; the musclebands are thick, fleshy, the dorsal ones are much wider than the ventral ones. Most of the bodywall is covered by the musclebands except a narrow band on the sides. The musclebands appear superficially to be divided but actual examinations shows they are merely furrowed. The gonads form two clusters of dichotomously divided tubes, attached closely behind the ring canal and opening dorsally near the attachment for the stone canal. In the type, collected March 4, the tubes were filled by large eggs.

The species differ from both *B. natans* (Sars) and *B. pourtalesi* (Théel) in its terminal or subventral anus and its crowded layer of spicules which consist of tables with a completed lace-like disk. Its greatest affinities seems to lie with *Bathyherpystikes punctatus* Sluiter from the East Indies. (1901, p. 37, pl. 7, figs. 12-13). The latter genus differs so slightly from *Bathyplotes* that is seems natural to withdraw it as a synonym. Whether the present species is identical with Sluiter's species cannot be decided without careful comparison

of the types. The spicules figured by Sluiter are at least distinctly different from those observed in *B. bigelowi.*

Amphigymnas bahamensis Deichmann

(Plate 32, figs. 1-10)

Amphigymnas bahamensis Deichmann, 1930, p. 107, pl. 9, fig. 9; pl. 10, figs. 1-6.

Diagnosis. — Large form (30 cm.); body elongate, synallactid-like, with four rows of large dorsal papillae, a lateral row of still larger papillae and an midventral double row of small tube feet. Tentacles 20, mouth ventrally placed, anteriorly overhung by the dorsal papillae; anus terminal. Skin thin, parchmentlike or more thick and gelatinous, according to the degree of contraction; rough to the touch. Inner anatomy similar to that of *Synallactes,* but the longitudinal musclebands are undivided.

Spicules large tables with well developed disk, mostly with four large central holes and a varying number of smaller marginal holes. Spire mostly four-pillared and of varying height often partly reduced. Besides a number of smooth perforated plates is presout with holes of approximately uniform size. Feet with or without an end plate and with numerous supporting rods, often with dentate edge, and smaller tables with 3-4 short pillars in the spire. In the dorsal papillae tables of varying size and curved supporting rods but apparently no end plate. Color in alcohol white.

Type. — U. S. N. M.

Type locality. — Between Bahamas and Cape Fear, 262 fathoms.

Distribution. —Known from the waters around Florida and Cuba, possibly more widespread.

Depth. — Between 240-320 fathoms.

Specimens examined. — The following material from the "Atlantis" cruises.

Station 3324 22° 08′ N., 81° 09′ 30″ W., 320 fathoms. 1 large specimen.

Remarks. — The single specimens measures about 30 cm. in length but is strongly contorted; it is about twice as large as the types.

The spicules differ considerably from those observed in the two types. There are fewer of the simple plates with holes of approximately uniform size while large tables with four central holes and stout four-pillared spire are numerous. Also the ventral feet were discovered to possess an end plate but these may merely have been missed in the types. It is possible that the perforated plates represent a juvenile character which gradually disappears (the types

were immature), while the larger tables gradually become dominating. Aside from these differences the specimen seems to agree well with the types when the difference in size is considered.

Pseudostichopus Théel

Pseudostichopus occultatus v. Marenzeller

Pseudostichopus occultatus v. Marenzeller, 1893, p. 15, pl. 4, fig. 9. Deichmann, 1930, p. 89.

Nec *Pseudostichopus occultatus* Hérouard, 1902, p. 14, pl. 2, figs. 4-11 (i. e. *P. marenzelleri* Hérouard, 1923, p. 25).

Diagnosis. — Small form (4-6 cm.), body normally covered by a coat of *Creseis* shells, etc. Tube feet larger along the sides, smaller in the interambulacra. A few perforated plates may be present near the anus; tentacles with curved rods; gonads with cross-shaped bodies, often with a central thickening.

Type. — Possibly in Vienna.

Type locality. — Eastern Mediterranean Sea.

Distribution. — Common in the Mediterranean Sea, also reported from the eastern coast of Spain. In the western part of the Atlantic reported from the waters around Cuba.

Depth. — In the eastern Atlantic taken from 363-2,180 meter. In the western Atlantic taken at 232 and 1,450 meters depth.

Specimens examined. — One individual from the "Atlantis" cruises.

Station 3344 21° 08′ N., 79° 56′ 30″ W., 690-700 fathoms. 1 specimen.

Remarks. — The members of the genus *Pseudostichopus* are most unsatisfactorily known and it is possible that some of the seven species recorded from the Atlantic Ocean may be united under one nome. The "Atlantis" specimen is completely covered by *Creseis*-shells. It is somewhat larger than a specimen previously collected near Cuba and also larger than the Mediterranean type specimen; these individuals measured respectively 2 and 4 cm.

Zygothuria Perrier

Zygothuria lactea (Théel)

Holothuria lactea Théel, 1886, p. 183.

Zygothuria lactea Deichmann, 1930, p. 198, pl. 8, figs. 8-9.

Zygothuria sp. Deichmann, 1930, p. 199, pl. 8, fig. 7.

Diagnosis. — Large form (6-15 cm. or more); body resembling a flattened sack; mouth ventral with about 20 tentacles, anus terminal;

tube feet few, large restricted to a ventro-lateral row on each side. Calcareous ring low; stonecanal attached to the dorsal integument; two Polian vesicles; intestine short; musclebands undivided; respiratory trees free with short lateral lobes; gonads attached closely behind the vascular ring as one tuft of divided tubes of varying size, the anterior tubes being smaller and less developed.

Spicules fragile tables, usually with six large holes in the disk and tall spire with three pillars and three diverging arms, mostly smooth; in some cases the spire ends in one central spine. Feet apparently without an end plate but with a few supporting rods; tentacles with smooth, curved or straight rods.

Mesothuria Ludwig, 1894

Mesothuria gargantua Deichmann

Holothuria verrilli Théel (partim), 1886 a, p. 6.
Mesothuria gargantua Deichmann, 1930, p. 95, pl. 7, fig. 1.

Diagnosis. — Large form (20 cm.), robust, with thick skin; stout cylindrical feet, scattered over the entire surface except on the anterior part of the ventrum, dorsally slightly smaller. Inner anatomy typical of the genus; sexes separate.

Spicules mostly huge tables with irregular disk with numerous holes and a four-pillared spire with few to many blunt teeth on the top. Feet with a vestige of an end plate or none at all; tables of almost the same size as in the skin. Color in alcohol ivory white.

Type. — M. C. Z.

Type locality. — Off Barbados, 720 meter.

Distribution. — West Indian seas.

Depth. — From 325-500 fathoms.

Specimens examined. — One large individual from the "Atlantis" cruises.

Station 3459 23° 21′ N., 80° 36′ W., 500 fathoms.

Remarks. — The single large individual agrees completely with the type and other specimens previously reported from the West Indian seas.

Mesothuria maroccana Perrier

Mesothuria maroccana Perrier, 1902, p. 312, pl. 16, figs. 32-35. Deichmann, 1930, p. 97 (list of synonyms).

Diagnosis. — Small form (4-8 cm.), with feet of unequal size, largest along the flanks, small but vell developed on the dorsum and

totally lacking on the ventrum. Inner anatomy typical of the genus; sexes separate.

Spicules regular tables, mostly with six holes; margin smooth or undulated; spire composed of three rods and ending in three diverging arms with few teeth. Feet with end plate and small tables of the same type as those in the skin, sometimes deformed. Color greyish brown with dark purplish tentacles.

Type. — Paris.

Type locality. — Off Morocco, 2,105 meter.

Distribution. — Eastern Atlantic, also widespread in the West Indian seas.

Depth. — Between 500-1,350 fathoms depth.

Specimens examined. — The following material from the "Atlantis" cruises.

Station	3366	20° 46′ N., 74° 59′ W., 625 fathoms.	1	specimen
„	3459	23° 21′ N., 80° 36′ W., 500 „	1	„

Remarks. — The single individual measures about 8 cm. in length. The species cannot be mistaken for any other form with its characteristic greyish brown color, purplish tentacles and completely smooth ventrum. The disk of the tables have frequently a more undulated outline than figured by Deichmann in 1930; similar tables were observed by Perrier.

Mesothuria verrilli (Théel)

Holothuria verrilli Théel, 1886 a, p. 6 (partim).
Mesothuria verrilli Deichmann, 1930, p. 93, pl. 6, figs. 1-8.
Nec *Mesothuria verrilli* Deichmann, 1926, p. 22, pl. 1, fig. 2 (juv. *Holothuria* sp.).

Diagnosis. — Large form (30 cm. or more) with delicate tube feet, almost thread-like, sacttered over the entire surface except the anterior part of the ventrum, often retracted. Inner anatomy typical of the genus; sexes separate.

Spicules, tables with regular to irregular disk and four-pillared spire, usually ending in four teeth or four bunches of few teeth. Feet with end plate and smaller tables, usually deformed. Color in alcohol, dirty brownish white.

Type. — M. C. Z.

Type locality.—Widespread in the West Indies, also known from the Eastern Atlantic, including the Mediterranean.

Depth. — From 382-1,000 fathoms.

Specimens examined. — The following material from the "Atlantis" cruises.

Station 3359 20° 38′ N., 74° 32′ W., 1,000 fathoms. 2 specimens, poorly preserved

Remarks. — The two specimen are externally so distorted that they can hardly be identified but the spicules resemble closely those of the type. The tables are much more delicate than those of *M. gargantua* and the ends of the pillars diverge, instead of being united by a wreath of spines as in *M. intestinalis,* the only other species with four-pillared tables of similar size, from the West Indian seas.

Type. — British Museum.

Type locality. — Off New Zealand.

Distribution. — Widespread in the Pacific and Atlantic Oceans. Common off the coast of New England and in the West Indian Seas.

Depth. — From about 400-1,000 fathoms.

Specimens examined. — The following material from the "Atlantis" cruises and from other trips off the eastern coast of the United States.

	Station	3359	20° 38′ N., 74° 32′ W.,	1,000	fathoms.	2	specimens
	„	3993	23° 93′ N., 80° 44′ W.,	580	„	1	„
"Atlantis"	August 4,	1938,	38° 59′ N., 72° 20′ W.,	980	„	1	„
„	„	„	38° 58′ N., 72° 19′ W.,	1,040	„	2	„
„	„	„	39° 00′ N., 72° 19′ W.,	1,050	„	2	„

Remarks. — The specimens intergrade to such an extent that it seems natural to withdraw the form which Deichmann in 1930 designated as *Zygothuria* sp., because it deviated slightly from the specimens hitherto described.

STICHOPODIDAE

Stichopus Brandt

Stichopus regalis (Cuvier)

(Plate 33, figs. 1-8)

Holothuria regalis Cuvier, 1817, p. 22, M. Sars, 1857, p. 152, pl. 2, figs. 78-81.
Stichopus regalis Lampert, 1885, p. 101 (complete list of references). Mortensen, 1927, p. 391, text figs. 232-233. Nobre, 1931, p. 145, pl. 13, fig. 4, text fig. 65, no. 2.

Diagnosis. — Large form (up to 36 cm.), with flat ventral side and vaulted dorsal side and a lateral margin of papillae; ventral side with numerous cylindrical feet, indistinctly arranged in three

bands; dorsal side with papillae. Mouth ventral with 20 tentacles; anus terminal; flanks thickened.

Calcareous ring low, radials with three anterior lobes and porteriorly deeply incised; Polian vesicle single; stonecanal with oblong head, attached in the mesentery. Gonads two tufts of tubes, attached near the vascular ring.

Spicules form a crowded layer of large tables with rounded disk with up to 50 holes, spire stout, tapering, composed of four pillars with several cross beams and lateral teeth. Feet with end plate and numerous rods with serrate edge of the serrations closed so they form rows of holes. Dorsal appendages with a group of small perforated plates instead of an end plate and with similar rods.

Type. — Possibly in Paris.

Type locality. — Mediterranean Sea.

Distribution. — Common in the Mediterranean Sea and in the Biscayan Bay, also taken off the Canaries and as far north as off the western coast of Ireland. It is now, for the first time, reported from the West Indian Seas.

Depth. — In the eastern Atlantic ranging from 5-400 meters (Mortensen).

Specimens examined. — The following material from the "Atlantis" cruises.

Station 3480 23° 10′ N., 81° 28′ W., 200 fathoms. 1 specimen

Remarks. — The diagnosis given above is based upon examination of the one individual (from Naples) which the M. C. Z. possesses, supplemented by information given by M. Sars (1857) and Mortensen (1927). The species appears to be one of these forms which is so well known that not detailed description ever has been compiled. The color, according to Mortensen is brownish, often with white spots on the dorsum; the underside is pale. Characteristic of both the Mediterranean specimen (which is much faded) and the "Atlantis" specimen is a number of small dark spots situated in the deeper layer of the integument.

The "Atlantis" specimen measures about 25 cm. in length but is so completely contorted that it possibly is abnormally stretched. It is impossible to trace the characteristic lateral brim of papillae although some obviously are present but the flanks are distinctly thickened. Dorsally as ventrally the appendages appear to be arranged as in the typical form. The inner anatomy which is fairly well preserved resembles that of the typical form from Naples. It is

apparently an older individual, the posterior prolongations on the calcareous ring are longer, the interradials stouter and the consistency of the ring more soft than in the Naples specimen. The stone canal has the same kind of oblong head and is attached in the same manner. The gonads form somewhat longer tubes but the shape and position agree with the conditions in the typical specimen.

The spicules have likewise been compared with those of the Naples specimen. They differ slightly in having a more irregular and undulating margin and the supporting rods are longer and more delicate. These differences may however be purely individual variations or due to difference in age or possibly the difference in the depth at which the animals have been taken. Comparison of a series of specimens taken at different depth may show that is the case. But with only one specimen available it seems unwise to segregate the eastern and western forms as separate species or varieties.

Stichopus badionotus Selenka

Stichopus badionotus Selenka, 1867, p. 316, pl. 18, fig. 26. Deichmann, 1930, p. 80, pl. 5, figs. 30-36.

For diagnosis, distribution, etc., see Deichmann, 1930, p. 80.

Specimens examined. — The following material from the "Atlantis" cruises. Matanzas Bay, Cuba, collected on the shore, March 20, 1938. 1 specimen.

Remarks. — The single individual measures about 20 cm. in length but is strongly contracted. The color is uniformly brown. The species represents one of the most common forms in the West Indies.

Holothria Linnaeus

Holothuria mexicana Ludwing

Holothuria mexicana Ludwig, 1875, p. 25. Deichmann, 1930, p. 74, pl. 5, figs. 15-20. Panning, 1934, p. 31, text fig. 24.

Diagnosis, etc. see Deischmann, 1939, and Panning, 1934.

Specimens examined. — Eight individuals of medium size (10-15 cm.) collected in Seguana Bay, Isle of Pine, Cuba, 1938.

Remarks. — The preserved specimens are all of the dark variety with brownish grayish dorsal side, greyish to yellowish ventral side and mostly dark pedicels. The spicules are typical of the species.

Holothuria lentiginosa v. Marenzeller

(Plate 34, figs. 1-7)

Holothuria lentiginosa v. Marenzeller, 1893, p. 6, pl. i, fig. 1; pl. 2, fig. 1. Panning, 1934, p. 82, fig. 68. Hérouard, 1929, pp. 53, 63.

Diagnosis. — Large form (up to 46 cm. in living condition), cylindrical body, fourth ventral with 20 tentacles, anus terminal Ventral side with scattered tube feet, completely retractile; dorsal side with contractile papillae and smaller tube feet, more or less papilliform.

Spicules, an external layer of tables with disk of varying size, largest in the appendages and with stout tapering spire. An inner layer of narrow smooth buttons, often twisted or incomplete. Ventral feet with end plate and straight supporting rods with perforated ends and often a number of lateral holes; dorsal appendages without end plate but curved supporting rods. Color light brown, paler on the ventral side; tip of appendages darker, often with a paler area around the base of the papillae.

Type. — Monaco.

Type locality. — Off the Azores, 130 meter depth.

Distribution. — Eastern Atlantic and the West Indian Seas.

Depth. — In the Eastern Atlantic from 67 and 250-389 meters depth. In the Western Atlantic reported from 175 and 250 fathoms.

Specimens examined. — The following material from the "Atlantis" cruises.

Station	2961	22° 07′ N.,	81° 08′ 30″ W.,	250-255	fathoms.	1	specimen
„	3465	23° 09′ N.,	81° 27′ W.,	175	„	1	„

Remarks. — The "Atlantis" specimens measure 13 and 18 cm. and are thus slightly larger than the type. (The record of 46 cm. is due to Hérouard who had occasion to examine a living specimen.) Externally the two individuals agree fairly well with v. Marenzeller's colored figure of the type made from life. The lateral and dorsal papillae are, however, completely retracted as are also the majority of the tube feet. There are apparently also many more tube feet in the "Atlantis" specimens which seem to be older than the type.

v. Marenzeller says little about the inner anatomy as most of the inner organs were lost. Dissection of the specimen from station 2,961 showed that the anatomy was not remarkable in any way. The calcareous ring is low, the stone canal has an oblong, soft, sack-like head which lies free to the right, and a single Polian vesicle is attached

to the ventral side of the vascular ring. The gonads form a bunch of slender tubes, dichotomously divided and attached near the oral end. A few eggs were lying in the tubes, indicating that spawning had recently taken (the specimen was collected in May).

The spicules resemble those figured by v. Marenzeller except that many tables have a smooth instead of a dentate margin. The tables show the same diversity of size as noted by v. Marenzeller; the largest tables are found in the appendages.

H. lentiginosa has been taken twice before in the Eastern Atlantic. It differs from all other species of the genus *Holothuria* known in that region and so far no species is known in the West Indies with which it may be confused. Bedford (1899, p. 145), noticed the similarity of the spicules with those of *H. pardalis* and suggested that it represents a variety of that widespread shallow water species.

Holothuria occidentalis Ludwig

(Plate 34, figs. 8-13)

Holothuria occidentalis Ludwig, 1875, p. 28, fig. 35. Deichmann, 1930, p. 60, pl. 2, figs. 9-17. Panning, 1934, p. 78, fig. 63 (copy of Ludwig's figure).

Diagnosis. — Medium-sized form (up to 15 cm. long) with 20 small tentacles, mouth ventrally placed; anus terminal. Ventrally few tapering feet, dorsally and laterally conical papillae. Skin thin but firm, packed with spicules. Calcareous ring with short posterior protuberances on the radials; stonecanal attached in the mesentery; Polian vesicles in varying numbers, the smaller ones, if present, often in clusters.

The spicules consist of an external layer of small tables; disk with small holes and blunt marginal spines, upward bent; spire stout with few teeth, often partly resorbed, forming four tapering points. An inner layer of small deformed knobbed buttons, often holes completely oblitterated. Appendages apparently without an end plate but with numerous supporting rods, straight or curved, often with a number of holes along the widened middle ortion. Color light brown, paler on the ventrum; dorsal papillae almost white.

Type. — Hamburg.

Type locality. — West Indian Seas.

Distribution. — Known from off the Virgin Islands (Th. Mortensen) and off Cuba.

Depth. — From about 200 fathoms.

Specimens examined. — The following material from the "Atlantis" cruises.

Station	3389	22° 32′ N.,	78° 08′ W.,	220 fathoms.	2	specimens.
„	3419	22° 45′ 30″ N.,	79° 00′ W.,	180 „	1	„
„	3420	22° 05′ N.,	79° 29′ W.,	250 „	1	„

Remarks. — The two specimens from station 3,389 were opened. They differ from the previously examined specimen from the museum in Copenhagen from the Virgin Islands, 200 fathoms) merely in having only one Polian vesicle. The gonads are almost ripe in these individuals, collected at the end of March; one is a female, the other a male; both measure about 15 cm. in length.

The spicules agree well with those figured in 1930, from the specimen in Copenhagen.

I have little doubt that Ludwig's two species are synonymous and that the present material represents his *H. occidentalis.* Strictly speaking the name *H. sulcata* should have been chosen since it appears before *occidentalis* but the description of the latter seemed to fit the specimen which was examined and it was first afterwards that it was realized that *H. sulcata* possibly could be identical with *H. occidentalis.*

Panning uses Ludwig's figures in his revision of the genus *Holothuria* but places the two species *occidentalis* and *sulcata* in two widely separated groups. Re-examination of Ludwig's types is therefore imperative to decide whether the two species are identical or not.

ORDER II — ELASIPODA

DEIMATIDAE

Deima Théel

Deima blakei Théel

Deima blakei Théel, 1886 a, p. 1, figs. 1-2. Deichmann, 1930, p. 115, pl. 10, figs. 7-11, pl. 11, figs. 1-3; 1936, p. 9.

Diagnosis. — Large form (up to 15 cm.), with flattened ventral side and vaulted back; mouth and anus ventrally placed; tentacles about 20 in number. Ventral side with a lateral row on each side of normally 11 tube feet, decreasing in size toward the posterior end; in front of the anus a few abortive tube feet are usually present. Dorsal side with normally 6 large conical papillae along the sides and 3-7 large conical papillae along the dorsal ambulacra.

Spicules large plates composed of a single layer; the perforations in the center are the largest; a few spines may be present and, in young individuals, a low central protuberance composed of a reticulum. Feet with elongate rods or plates; end plate apparently lacking. Color in alcohol white; in life brilliant red.

Type. — M. C. Z.

Type locality. — Off St. Vincent, 573 fathoms.

Distribution. — In the West Indian Seas known from the type locality, south of Jamaica, near the Bahamas and around Cuba. In the Eastern Atlantic previously reported from near the Azores.

Depth. — From 573-1,519 fathoms.

Specimens examined. — Several individuals from the "Atlantis" cruises.

Station	3358	20° 40′ N., 74° 32′ W., 975 fathoms.		1 specimen, small, infested with endoparasitic gasteropod
„	3366	20° 46′ N., 74° 59′ W., 625	„	5 specimens, 4 large, 1 small
„	3369	20° 49′ N., 75° 98′ W., 600	„	2 specimens, large

Remarks. — The abundance of material shows the same variability of the number of the dorsal papillae and number of lateral feet as indicated by Théel. Most noteworthy was to find that in the youngest individual the large perforated plates often had a low reticulated knob near the center while the plates in the larger individuals had merely a few scattered spines on the outer side.

The small individual was furthermore interesting in that it was infested with one of the rare endoparasitic gasteropods. The parasite was attached to the ventral side of the body cavity and to the intestine.

Orphnurgus Théel

Orphnurgus asper Théel

Orphnurgus asper Théel, 1882, p. 82, pl. 15; pl. 34, figs. 15-16; pl. 38, fig. 10; pl. 41, fig. 3, pl. 44, fig. 3; 1886 a, p. 2. Deichmann, 1930, p. 117, pl. 11, figs. 4-8.

Diagnosis, etc. See Deichmann, 1939, p. 117.

Specimens examined. — Several from the "Atlantis" cruises.

Station	3365	20° 49′ N., 74° 59′ W., 600 fathoms.		2 specimens.
„	3366	20° 46′ N., 74° 59′ W., 625	„	7 „

Remarks. — The material measures from 7 to 19 cm. in length. The characteristic short, strongly spinous rods makes it easy to recognize the species. It is apparently quite common in deeper water in the West Indian Seas.

Station 3367	20° 46′ N., 70° 02′ W.,	640 fathoms.	6	specimens.
„ 3369	20° 49′ N., 75° 08′ W.,	600 „	1	„

PSYCHROPOTIDAE

BENTHODYTES Théel

BENTHODYTES TYPICA Théel

(Plate 35, figs. 1-2)

Benthodytes typica Théel, 1882, p. 103. Deichmann, 1930, p. 123.

Diagnosis. — Small form (10-15 cm. long), with a broad lateral brim of alongated tube feet; mouth ventral with 20 tentacles; anus terminal; ventrum with a double row of tube feet along the midventral ambulacrum; dorsum with a few papillae.

Spicules simple pointed rods, slightly curved, often with a central swelling; ends slightly spinous. Color intensive reddish or purplish.

Type. — British Museum.

Type locality. — Off Gibraltar.

Distribution. — Wide spread in the Eastern and Western Atlantic.

Depth. — From 1,400-3,514 meter.

Specimens examined. — About 20 individuals or fragments, all poorly preserved from the "Atlantis" cruises.

					Fathoms		
Station	2966	22° 47′	N., 80° 24′	W.,	2,125.	5	small specimens
„	2967	19° 47′	N., 75° 06′	W.,	1,530.	5	„ „
„	2967A	19° 47′	N., 75° 06′	W.,	1,580-1,800.	2	„ „
„	2967B	19° 45′ 30″	N., 74° 57′ 30″	W.,	1,330-1,650.	5	„ „
„	2976	21° 19′	N., 76° 05′	W.,	1,450.	3	„ „
„	3344	21° 38′	N., 80° 12′	W.,	1,440.	5	„ „
„	3355	19° 30′	N., 75° 00′	W.,	1,070-1,950.	10	„ „

BENTHODYTES LINGUA Perrier

(Plate 35, figs. 3-4)

Benthodytes lingua Perrier, 1898, p. 902; 1901, p. 466, pl. 12, figs. 1-2, pl. 21, figs. 1-9. Deichmann, 1930, p. 124.

Benthodytes sp. Théel, 1886 a, p. 3.

Diagnosis. — Large form (25-30 cm.), with narrow marginal brim of papillae; mouth ventrally placed, with 15 tentacles; anus terminal. Ventral side with a double row of tube feet along the midline; dorsal side with few papillae, often inconspicuous.

Spicules huge crosses with inward curved arms and an outer central projection, often divided into two or three arms; surface of spicules rough, spinous. Tentacles with simple spinous rods. Color varying shades of red or purplish.

Type. — Paris.

Type locality. — Off Morocco.

Distribution. — Reported once from the Eastern Atlantic; apparently common in the western part.

Depth. — From 860-2,200 meter.

Specimens examined. — A few individuals, all poorly preserved from the "Atlantis" cruises.

Station	2969	19° 47′ N., 75° 54′ W.,	1,145-1,075 fathoms.	1	specimen
„	3359	20° 38′ N., 74° 32′ W.,	1,000 „	2	„

Remarks. — The species was originally listed by Théel as *Benthodytes* sp. from the West Indies. Its spicules are so characteristic that it cannot be confused with any other species. The crosses measure more than 1 mm. in diameter and may easily be observed with the unaided eye.

Euphronides Théel

Euphronides violacea Perrier

Euphronides violacea Perrier, 1896, p. 102, 1901, p. 438, pl. 20, fig. 14. Deichmann, 1930, p. 128.
Euphronides deressa var. *minor* (partim) Théel, 1886 a, p. 2.
Euphronides assimilis Théel, 1886, p. 3.

Diagnosis. — Large form (up to 20 cm.); resembles the northern form *E. cornuta* Verrill but has only four pairs of dorsal papillae. Outer and inner features typical of the genus.

Spicules, dorsally large crosses with arms inward bent and a central smooth conical projection surrounded by four shorter spines; ventrally, smaller crosses, often almost flat, slightly spinous or smooth rarely with a trace of an external central projection. Color reddish or purplish.

Type. — Paris.

Type locality. — Off Morocco.

Distribution. — Eastern and Western Tropical Atlantic.

Depth. — From 1,180-4,060 meter.

Specimens examined. — The following material from the "Atlantis" cruises.

Station	3355	19° 50′ N., 75° 00′ W.,	1,070-1,950	fathoms.	1 specimen
„	3379	21° 49′ N., 76° 43′ W.,	910	„	1 „

Remarks. — The species is closely related to the northern form, *E. cornuta* Verril, described from off the eastern coast of the United States. It differs in the lower number of dorsal appendages (which in this case could not be ascertained) and the more simple crosses in the skin of the ventral side. Further investigations may reveal that the characters listed are inconstant and that the two forms intergrade. In that case Verril's old name has the priority.

Euphronides kernervei (Hérouard)

(Plate 35, figs. 9-12)

Psychorpotes kerhervei Hérouard, 1902, p. 27, pl. 4, figs. 1-9; 1923, p. 104, pl. 3, figs. 4-5.
Benthodytes kerhervei Deichmann, 1930, p. 125.

Diagnosis. — Small form (6-8 cm.), with insignificant unpaired dorsal appendage; lateral feet small, united into a narrow brim; midventral ambulacrum with a doube row of tube feet; mouth ventral with about 16 tentacles; anus ventrally placed. (The arrangement of the dorcal paired papillae is completely unknown.)

Spicules strongly spinous crosses, occasionally with a larger external central spine and smaller basal spines, often bifid.

Type. — Monaco.

Type locality. — Between the Azores and Portugal.

Distribution. — Known from the Eastern and Western Tropical Atlantic.

Depth. — From 3,825-5,505 meter.

Specimens examined. — The following material from the "Atlantis" cruises.

Station 2966 20° 46′ N., 74° 59′ W., 625 fathoms. 1 specimen, poorly preserved

Remarks. — The specimen measures about 8 cm. in length; the color is deep purplish. It is exceedingly poorly preserved but resembles a slightly smaller specimen taken near St. Croix, Virgin Islands and described by Deichmann in 1930. Some of the spicules in the present specimen were found to approach those of the *Eupro-*

nides-type and the species has therefore provisionally been switched over to that genus. It is distinctly different from all other Psychropodidae known from the West Indies.

ORDER III — DENDROCHIROTA

The majority of this order of plankton feeders are shallow water forms, and only few members of this comparatively modern group have descended into deeper water. The "Atlantis" cruises to Cuba secured only one species, previously reported from that region. From the eastern coast of the United States two deep water species were secured by the Atlantis summer cruises.

CUCUMARIIDAE

SPHAEROTHURIA Ludwig, 1894

Ypsilothuria E. Perrier, 1886.(*)
Nec *Ypsilothuria* Hérouard, 1923, p. 118 (i. e. *Echinocucumis*).

Diagnosis. — Small dendrochirotes with globose, rigid body, few cm. in diameter and with mouth and anus placed on shorter or longer protuberances. Tentacles almost or completely unbranched, of unequal size and in one species reduced in number (?). Feet delicate, cylindrical, few in number, in five more or less incomplete rows.

Skin covered by huge plates, visible with the naked eye; plates composed of more than one layer except in very young individuals; holes in plates small. The majority of the plates carry a stout pillar or spine, more or less centrally placed. Some of the plates along the ambulacra are perforated for the passage of the tube feet. Deep water forms.

Type species. — *Sphaerothuria bitentaculata* Ludwig.

Remarks. — The genus *Ypsilothuria* Perrier is undoubtedly a synonym of Ludwig's genus although Perrier's description is not very detailed. The chief differences between the two genera is supposed to be the lower number of tentacles in *Sphaerothuria* but that may possibly be a variable character. It seems more important that both

(*) The name *Sphaerothuria* is retained although it is a complete synonym of *Ypsilothuria*, published by E. Perrier in 1886, attached to the two species *attenuata* and *talismani* with figures, but no diagnosis was given and the descriptions are not sufficiently detailed to make identification positive as Ludwig pointed out (1894, p. 155). R. Perrier (1902) placed *Sphaerothuria* as a synonym of *Ypsilothuria* at the same time as he describes the latter as a new genus and also designates *attenuata* and *talismani* as new species. Neither the genus nor the two species are recognized as such in the Zoological Record for 1886 although Perrier's book is listed and all the new species and genera, dsecribed by Theél and others, are given.

genera have plates of complex structure and tube feet which pass out through a pore in the scales. In the related genus *Echinocucumis* Sars which also occurs in the Atlantic Ocean (and sometimes has been mistaken for *Sphaerothuria*), the plates have large holes and are always simple, composed of only one layer, and the tube feet pass out trough an indentation in the margin of the scale. Also the spire is almost invariably eccentrically placed.

Hérouard (1923) claims that *Ypsilothuria* is a synonym of *Echinocucumis* while he upholds *Ephaerothuria* as a distinct genus. His conclusion is based upon the finding of a very young "*Echinocucumis*" (2-3 cm. long with 4-5 large ventral feet and less than 10 tentacles) in shallow water, north of Siberia. That specimen was found to have plates with small holes, as the deep water *Ypsilothuria*, while the fulgrown *Echinocucumis* has large holes, hence he holds that the holes increase in size this species, contrary to the normal procedure. But it seems very doubtful whether his "*Echinocucumis*" is correctly identified. The description suggests a young individual of *Cucumaria frondosa* (Gunnerus) of which adult individuals were taken in the same haul. If that is correct, the whole involved chain of proofs is reduced to nothing, and no grounds remain for referring *Ypsilothuria* to the synonymy of *Echinocucumis*.

Sphaerothuria talismani (Perrier)

Ypsilothuria talismani E. Perrier, 1886, p. 286, text fig. 204. R. Perrier, 1902, p. 318, pl. 12, figs. 9-10, text fig. 12.
Sphaerothuria talismani Deichmann, 1930, p. 154, pl. 19, fig. 3.

Diagnosis. — Small form (diameter of globular body up to 1 cm.); scales few with large spine, centrally placed; reticulum dense, rather fine and appears soon on the scales. Tentacles 10, of very unequal size, one on each side being much larger than the rest.

Spicules in tentacles curved rods, slightly spinous, with or without a few minute holes in the ends.

Type. — Paris.

Type locality.

Distribution. — In the Easterh Atlantis ranging from the coast of France to Cape Good Hope; in the western part reported from the Caribbean Sea and off the coast of New England.

Depth.

Specimens examined. — The following material from the "Atlantis" summer cruises.

July 26, 1939, Tow 6, 40° 05′ N., 68° 05′ 1,105-1,125 fathoms. 1 specimen

Remarks. — The single individual differs markedly from the specimens of *S. asperrima* in the lower number of spines and the finer reticulum on the scales. It agrees in all essentials with the specimens previously taken in the West Indian region (in the M. C. Z.).

Sphaerothuria asperrima Théel

Echinocucumis asperrima Théel, 1886 a, p. 10.
Echinocucumis typica Théel, 1886, p. 118 (*partim*). Nec *E. typica* Sars (*E. hispida* Barrett).
Sphaerothuria asperrima, Deichmann, 1930, p. 156, pl. 19, figs. 1-2.

Diagnosis. — Comparatively large form (diameter of the globose body up to 2 cm. in diameter); scales large, thick, with relatively small holes and secondary reticulum which appears comparatively late. Spire composed of several pillars, more or less fused. Tentacles ten, with plates perforated by small holes and undulated or scalloped edge.

Type. — M. C. Z.

Type locality. — Of Isles of Pines, Cuba, 158 fathoms.

Distribution. — Known from off Cuba, Florida and Barbados, possibly more widespread in the West Indies.

Specimens examined. — The following material from the "Atlantis" cruises.

Station	2960	22° 07′	N.,	81° 08′ 30″	W.,	270	fathoms.	1	specimen
„	2962	22° 07′	N.,	81° 08′	W.,	200-210	„	1	„
„	2962c	22° 07′	N.,	81° 08′	W.,	210	„	6	„
„	2982	22° 44′ 30″	N.,	78° 41′	W.,	150-180	„	1	„
„	3328	22° 08′	N.,	81° 10′	W.,	260-275	„	1	„
„	3330	22° 09′ 30″	N.,	81° 10′ 30″	W.,	280-263	„	1	„
„	3332	22° 09′ 30″	N.,	81° 11′	W.,	175-225	„	1	„
„	3374	22° 45′	N.,	75° 19′	W.,	300	„	1	„
„	3375	20° 45′	N.,	75° 20′	W.,	230	„	3	„
„	3376	20° 44′ 30″	N.,	75° 18′	W.,	285	„	1	„
„	3392	22° 35′	N.,	78° 18′	W.,	225	„	1	„
„	3475	23° 18′	N.,	80° 48′	W.,	400	„	1	„

Remarks. — The specimens agree well with the type. The spire is frequently almost completely fused into a solid rod, probably due to age but similar solid spires were observed also in the type, especially near the anterior and posterior ends.

The species occurs in as shallow water as *Echinocucumis hispida* (Barrett) but the latter is easily recognized on account of its simple

plates with large holes. From the closely related form, *S. talismani*, which normally seems to inhabit slightly deeper water, it is distinguished by its more numerous and more coarsely reticulated plates and the broad plates in the tentacles.

PSOLIDAE

Psolus Oken

Psolus pourtalesi Théel

Psolus pourtalesi Théel, 1886 a, p. 14, pl. 1, fig. 6. Deichmann, 1930, p. 188, pl. 20. figs. 5-7.

Diagnosis. — Small form (few cm. long), with numerous (about 20) imbricating smooth scales; no oral or anal operculum. Sole with marginal pedicels.

Spicules in sole thinly scattered plates varying from crosses to oval buttons with 3-5 holes, usually completely smooth; pedicels with end plate and heavy supporting rods and plates.

Type. — M. C. Z.

Type locality. — East of Nantucket (41° 24′ 45″ N., 65° 35′ 30″ W.), 1,242 fathoms.

Distribution. — As far as known only reported from the western part of the Atlantic Ocean.

Depth. — From 1,230-1,280 fathoms.

Specimens examined. — The following material from the "Atlantis" summer cruises.

1939, July 27	Tow 8	40° 01′ N.,	68° 06′ W.,	1,230 fathoms.	6 specimens
1939, July 27	Tow 9	39° 09′ N.,	68° 05′ W.,	1,280 „	38 „

Remarks. — The specimens agree completely with the types in the M. C. Z.

ORDER IV — MOLPADONIA

Diagnosis. — Holothurians with barrel-shaped body, terminal mouth, surrounded by a well defined circle of fairly small tentacles, (sometimes claw-shaped); terminal anus, often placed on a longer or shorter "tail". Appendages usually totally lacking except for the minute anal papillae (one genus has a few whip-like papillae on the dorsum and a few degenerate appendages are stated to be present in certain other genera (?). Skin thin but tough, fibrous. Calcareous ring firmly built, often with short bifid prolongations on the radials; tentacles ampullae present or reduced. Stone canal opens

to the exterior in the dorsal midline or the head hangs free in the body cavity. Respiratory trees present; musclebands simple or divided, no true retractors present; genital organs in two tufts of tubes, often opening on a shorter or longer papilla in the dorsal midline.

Spicules of various kind, as one or three pillared tables, plates, cross-cups or irregular bodies. Dark red or brown "phosphatic bodies" are present in many forms, often increasing in number with age while the spicules sometimes become reduced. A few forms seem to lack spicules entirely. Anchors placed on a rosette of racquet-shaped plates, are present in some forms but disappear often with advancing age. Shallow water to deep sea forms.

Remarks. — The Molpadonia was, in 1908, regarded by H. L. Clark as a family of the order Actinopoda, now considered obsolete. The order is here divided into the families Gephyrothuriidae, Caudinidae, Molpadiidae and Eupyrgidae, essentially the same arrangement as that proposed by Heding in 1931. His orders Gephyrothurioidea and Molpadioidea are, however, rejected. Some of the forms in the Gephyrothurioidea are undoubtedly merely synallactids (hence the erroneous conception of connecting the Molpadonia with the Synallactidae) and the two remaining species, both belonging to the genus *Gephyrothuria,* differ so little from the Molpadioidea that there are no grounds for keeping them separate. The name Molpadioidea represents merely a synonym of the old name Molpadonia.

Three of the four families have representatives in the Western Atlantic, while the fourth is exclusively Arctic.

KEY TO THE FAMILIES ON THE ORDER MOLPADONIA

1. Tentacles with unpaired terminal digit and a few lateral digits or simple, in one case claw-shaped. 2

1. Tentacles with no unpaired terminal digit, usually one or two pairs of digits. 3

2. Tentacles simple; tentacle ampullae lacking; spicules comparatively large tables with numerous holes in the disk. Small forms few cm. long. Arctic.. . . . . [4. *Eupyrgidae* Semper 1868]

2. Tentacles with more than one digit, or claw-shaped; tentacle ampullae present (very small in some species); spicules derived from tables with solid or three-pillared spire; tail with

tables with round to oblong disk or fusiform rods. Spicules sometimes reduced with age or possibly totally lacking. Dark red egg-shaped "phosphatic bodies" often present; in some species anchors and racquet-shaped plates, frequently reduced with age. Mostly large forms. . . . . 3. *Molpadiidae* J. Müller 1850

3. Dorsal side with a few whip-like papillae; spicules lacking. . . . . 1. *Gephyrothuriidae* n. fam.

3. Dorsal side without whip-like papillae. Spicules large tables or plates, or cross-cups or irregular bodies. No phosphatic bodies but discoloration of the skin may occur in older individuals of some forms. . . . . 2. *Caudinidae* Heding 1931

REVISED LIST OF THE SPECIES OF MOLPADONIA KNOWN FROM THE ATLANTIC OCEAN, INCLUDING THE WEST INDIAN SEASS AND THE ARCTIC OCEAN

GEPHYROTHURIIDAE.

Gephyrothuria glauca H. L. Clark(*)

CAUDINIDAE.

Caudina arenata Gould.
Paracaudina obesacauda H. L. Clark.
Hedingia albicans (Théel) (syn. *Haplodactyla* Heding 1935, *nec* Grube 1840, nec Heding 1931).

MOLPADIIDAE.

Molpadia agassizi (Théel).
**Molpadia arctica* v. Marenzeller.
Molpadia barbouri spec. nov.
Molpadia blakei (Théel) (syn. *Paratrochostoma spiniferum* Heding, 1931, 1935).
**Molpadia borealis* (Sars).
Molpadia cubana spec. nov. (syn. *Trochostoma antarcticum* Théel (partim) 1886 a and *Molpadia oolitica* (partim) Deichmann, 1930).
**Molpadia maroccana* (Perrier) (i. e. *Paramolpadia diploa* and *capensis* Heding, 1931, 1935).
Molpadia musculus (Risso) (syn. *Eumolpadia asaphus* Heding, 1931, 1935).
Molpadia oolitica (Pourtalès) (syn. *Trochostoma turgidum* Verrill, 1885).
Molpadia parva (Théel).

EUPYRGIDAE.

Eupyrgus scaber Lütken.

(*) *G. europeensis* Hérouard is regarded as a synallactid while *Molpadiodemas acaudum* Heding appears to be a synonym of *Pseudostichopus atlanticus* Perrier.

Remarks. — The 21 species listed by Heding in 1931, including some not mentioned in his paper and two new species, are here reduced to 15. All the species listed are discussed except three marked with an. Regarding these, see Deichmann, 1936, p. 460 and 1938, pp. 1-5. While the two first mentioned species are undoubtedly restricted to the Arctic Seas and the northern part of the Atlantic Ocean, the third may be expected to belong to the West Indian fauna.

1. **Gephyrothuriidae** fam. nov.

Diagnosis. — Small or moderately large forms with terminal mouth surrounded by a circle of 15 tentacles with two pairs of lateral digits. Body barrel-shaped with a few pairs of whip-like papillae on the dorsal side and some abortive pedicels near the ends (?). Anus terminal, apparently never placed on a distinct tail as in most of the other Molpadonia. Calcareous ring simple, fairly tall with places firmly united; tentacle ampullae lacking; stone canal small, not attached to body-wall, possibly reduced in one species (?); musclebands undivided; gonads opening in the dorsal midline; genital papilla present or lacking.

Spicules seems to be totally lacking. Color greyish or white. Deep water forms.

Remarks. — The family includes one genus with two, possibly only one, species. A third species referred to this group is undoubtedly a young synallactid and the other genus recently created and included in the order Gephyrothuroidea Heding, viz., *Mopadiodemas* Heding with one species *M. acaudum* Heding, seems to be a synonym of *Pseudostichopus atlanticus* Perrier. (Compare Heding's detailed description and figures with Théel's equally careful description and figures of the closely related form *P. mollis* Théel from the Pacific Ocean.)

Genus Gephyrothuria Koehler & Vaney

Syn. *Himastlephora* H. L. Clark, 1908.

Diagnosis. — As for the family.

Type species. — *G. alcocki* Koehler & Vaney.

Remarks. — The family contains only one genus with one or two species. The type came from the Indian Ocean, *G. glauca* (H. L. Clark) was described from the Western Atlantic while *G. europeensis*

Hérouard, from the Eastern Atlantic is undoubtedly a synallactid, probably a young *Pseudostichopus* as is also Heding's *Molpadiodemas acaudum* (See above).

The genus *Gephyrothuria* was established in 1902 by Koehler & Vaney who described a single species from the Indian Ocean. The two authors placed the species near to the Elasipoda but commented on the resemblance to the molpadids. In 1908 H. L. Clark described another species from the Atlantic Ocean but placed it in another, new genus, *Himasthlephora,* because his four individual apparently had a caudal appendage which was not present in *Gephyrothuria.*(*) He referred goth genera to the Molpadonia, or Molpadiidae as he then called the group.

In 1923 Hérouard described a small holothurian from the Eastern Atlantic and due to its lack of spicules and the presence of a few dorsal papillae, he referred it to *Gephyrothuria* and described it as a new species, *G. europeensis.* At the same time he relegated *Himasthlephora* to synonymy. Superficially his description may fit a *Gephyrothuria* and Deichmann wrote in 1930 that apparently there was no differences between the two Atlantic species of that genus. But a more critical study of Hérouard's description and especially of his figures, reveals that the animal in question must be a yonug synallactid, probably a *Pseudostichopus.* This explains why Hérouard was so convinced that *Gephyrothuria* belonged near the synallactids and exhibited so many similarities with *Pseudostichopus.* Heding followed Hérouard and claimed (1931) that the Molpadonia had close affinities with the Synallactids. He had, however, no occasion to see either the type of *G. alcocki*(**) or of *C. glauca* but based obviously his studies on Hérouard's description of what is not a Molpadonia. At the same time Heding established a new genus,

(*) Actually Koehler & Vaney mentions an evaginated fragment of the intestine in their species.

(**) Heding's assuption (1935, p. 77) that *G. alcocki* has 20 tentacles instead of 15, is based on Koehler & Vaney's statement that the calcareous ring has three anterior points between the attachments for he longitudinal muscles on the radials. Heding feels that this would must correspond with 20 tentacles and refers furthermore to *Molpadiodemas acaudum* Heding which has 20 tentacles. But the latter is a synallactid and Koehler & Vaney may possibly have made an error in counting the anterior teeth. The figure and description suggest a typical molpadid and they state expressly that it has 15 tentacles, or Heding may have misinterpreted their description.

In this connection it may be mentioned that the number of tentacles in the Molpadonia is always easy to count, even when they are contracted. They are so few in number, so well spaced and arranged in a regular circle that one never encounters the difficulties in estimating the correct number that one does in many other groups.

Molpadiodemas with a single species, *M. acaudum* whichs eems to agree in every respect with *Pseudostichopus atlanticus* Perrier, also from the Atlantic Ocean.

Gephyrothuria glauca (H. L. Clark)

Himasthlephora glauca H. L. Clark, 1908, p. 40, 184, pl. 13, figs. 1-4. Heding, 1931, p. 276.

Gephyrothuria glauca Deichmann, 1930, p. 203.

Diagnosis. — As for the genus. Differ from the type species in minor detail such as the presence of a large genital papilla and the lack of a stone canal (?)(*)

Type. — U. S. N. M.; paratype in M. C. Z.

Specimens examined. — A paratype in the M. C. Z.

Remarks. — Aside from the "caudal appendage" which Clark himself was inclined to regard as an artefact (while Hérouard 1923 and Deichmann, 1930 both decided it was merely an evagination from the intestine) the species differs very little from the type species. More material may possibly prove that they are identical and in that case the name *G. alcocki* will stand.

Hérouard's *G. europeensis* was regarded as a syninym of *G. glauca* by Deichmann in 1930 but a more close study of his description with his repeated emphasiz laid on the similarities with *Pseudostichopus* makes it seem more probable that *G. europeensis* belongs in that genus and possibly represents a young individual of the common form in the Atlantic *P. atlanticus* Perrier. That explains why Héroaurd felt convinced that his *Gephyrothuria* is related to the synallactids, while Koehler & Vaney emphasize the similarities of *G. alcocki* with the Molpadonia, viz., the shape of the body, the terminal circule of 15 tentacles, etc.

2. Caudinidae Heding, 1931

Diagnosis. — Medium-sized to large forms, with barrel-shaped body, terminal mouth surrounded by a circle of small tentacles, with no terminal digit but 1-2 pairs of lateral digits. Anus terminal, placed on a shorter or longer caudal prolongation, which in some

(*) Clark was unable to find a stone canal in *G. glauca* but is material was quite old, collected in 1886, so the small amount of calcareous mass may ave dissolved.

Clark's figure of the calcareous ring is similar to the description given by Koehler & Vaney for *G. alcocki* and I think the two authors description of three points between the attachment of the longitudinal muscles indicaes the presence of 15 tentacles and not of 20 as Heding suggests (1935, p. 78). See above p. ...

forms is practically absent. No appendages except the anal papillae. (In one form abortive pedicels are stated to be present (?). Calcareous ring firm, with or without short posterior prolongations; tentacle ampullae present; stone canal with head free in body cavity; longitudinal muscles divided; no true retractors present but the free edges of the anterior portion may simulate retractors; gonads as two tufts of tubules, the external opening in the dorsal midline behind the tentacles, sometimes on a distinct papilla.

Spicules large tables or perforated plates, small cross-cups or irregular bodies of variable form. In some forms the spicules are reduced with age, in others they seem almost to be lacking. No phosphatic bodies are present. Color white, grey, or with brownish spots.

Remarks. — The family comprises four genera. Heding (1931) took the initiative to divide the old genus *Caudina* into two, *Caudina* and *Paracaudina,* originally *Pseudocaudina* but changed the same year (1931), and this division was accepted by H. L. Clark (1935). Deichmann (1936) divided the genus *Caudina* into two, a genus comprising the shallow water forms, *Caudina,* and one comprising the deep-sea forms, *Hedingia.* Examination of the type material of *Acaudina* and *Aphelodactyla,* both of H. L. Clark, in the Zoological Museum in Amsterdam showed that these two genera were synonomous and as *Acaudina* precedes the other name, it must be the one accepted. *Acaudina demissa* (Sluiter) may possibly be found to be merely a very large individual of the common East Indian species, *A. molpadioides* (Semper). Contrary to the current belief, it was found that the latter had one pair of small digits, like *A. demissa.* A number of species of *Acaudina* have been described from the East Indies, in the course of time but Sluiter proved (1912) conclusively that the different forms were all identical. The latter paper undoubtedly escaped Heding's attention in 1931, as he lists all the species included in Clark's monograph. Two additional species were described by H. L. Clark (1938).

KEY TO THE GENERA OF THE FAMILY CAUDINIDAE

1. Tentacles with one pair of digits. Spicules almost lacking. . . . . [4. *Acaudina* H. L. Clark]
1. Tentacles with two pairs of digits. . . . . 2.
2. Spicules as minute cross-cups. . . . . 2. *Paracaudina* Heding.
2. Spicules as larger tables or plates. . . . . 3.
3. Spicules comparatively small tables and knobbed buttons, reduced in one species. . . . . 1. *Caudina* Stimpson.
3. Spicules large tables or plates with numerous holes. Deep water forms. . . . . 3. *Hedingia* Deichmann.

Remarks. — The genus *Acaudina* is exclusively East Indian. The three other genera have each one representative in the Western Atlantic. Only one was secured by the "Atlantis" expeditions but all three species are briefly discussed here.

1. Caudina Stimpson, 1853

Diagnosis. — Molpadonia with 15 tentacles with two pairs of digits, the distal pair longer, but no terminal unpaired digit. Body barrel-shaped with a longer or shorter caudal portion. Calcareous ring with fairly short posterior prolongations on the radials. Tentable ampullae present; single Polian vesicle; stone canal with roundish head, not opening in the dorsal integument. Longitudinal muscle bands divided, no true retractors present although the free edges of the anterior portion may project as ridges into the body cavity and give the impression of retractors, especially in older individuals. Third loop of intestine held in position by "pseudomesenteries", powerful strands attached to the lateral walls. Respiratory trees well developed. Gonads forming two tufts of long tubes, several times divided and opening behind the crown of tentacles.

Spicule tables with usually four pillars in the low spire which ends in numerous teeth; disk with four central holes and eigth to ten marginal holes; edge often knobbed. Besides a varying number of knobbed buttons, usually with two larger and two smaller holes. Spicules almost completely reduced in one species.

Type species. — *Caudina arenata* (Gould). ,

Remarks. — The genus has been recently delimited to include only the type species from the coast of New England, a closely related form from the Japanese waters, *C. simile* Augustin, and *C. arenicola* (Stimpson) from the estuaries along the coast of Southern California and also taken from off Cedros Island, Lower California at 44 fathoms depth. The last mentioned species is usually described as lacking spicules almost completely and its position has therefore been somewhat doubtful. Oestergren (1907, p. 210, footnote), was the first to call attention to the presence of the pseudomesenteries in this species as well as in the related form, *C. arenata,* and explained their presence as caused by the burying habits of these two shallow water forms, while the deep water form, *C. arenata* var. Théel (i. e. *Hedingia albicans* Théel), lacked these structures. Recently it has been discovered that *C. arenicola* possesses spicules which are very similar to those of the somewhat smaller type species *C. arenata* (See Deichmann, 1938, p. 112).

Caudina arenata (Gould)

Chiridota arenata Gould, 1841, p. 345. H. L. Clark, 1908, p. 174, pl. 10, figs. 1, 2, 11.
Caudina arenata Deichmann, 1930, p. 200, pl. 24, figs. 2-5. Heding, 1935.

Diagnosis. — As for the genus. Posterior end of the body distinctly tapering.

Spicule tables (diameter 0.09-0.14 mm.) and smaller knobbed buttons. Color of preserved specimens white. Shallow water form, usually taken at about 35 fathoms deph buried in the sand or mud.

Type. — Lost.

Type locality. — Coast of New England, washed up on the shore after storms.

Distribution. — Known only from the coast of New England, where it seems fairly common.

Depth. — From about 35 fathoms depth.

Specimens examined. — None from the "Atlantis" cruises.

Remarks. — Heding has recently studied this species and figured spicules from both old and young individuals which show the considerable changes which the spicules undergo. The so-called buttons are very likely merely imperfectly developed tables. The species may reach a length of 25 cm. most individuals measure about 10-15 cm. It is possible that very old individuals (which never have been available), may show the same degeneration of the spicules as that known from *C. arenicola* (Stimpson) and also to some extent occurs in the related genus *Paracaudina* where the typical cross-cups gradually becomes substituted by irregular four-holed plates.

The species seems to occur at a rather inaccessible depth, that is, at about 35 fathoms. It is unfortunate that it apparently never occurs in shallow water like the Japanese form of *Paracaudina chilensis* for it would probably be an ideal animal for experimental wory. An excellent description of its anatomy was given by Gerould in 1895.

2. Paracaudina Heding, 1931

Caudina auctores.
Pseudocaudina Heding, 1931 (preoccupied).

Diagnosis. — Medium sized to large; as *Caudina* but with small cross-cups or small plates with a few central holes; spicules sometimes degenerating more or less with advancing age. No phosphatic bodies

but a diffuse reddish or brownish pigment may be found in older individuals. Shallow water forms.

Type. — *Paracaudina chilensis* (J. Müller).

Remarks. — The genus has a number of representatives in the Pacific Ocean and one in the West Indies.

Paracaudina obesacauda (H. L. Clark)

Caudina obesacauda H. L. Clark, 1908, p. 38, 1935, p. 176, pl. 9, figs. 1-5. Deichmann, 1930, p. 201, pl 201, pl. 24, figs. 6-8; 1938, p. 23.

Diagnosis. — As the type species *P. chilensis* (J. Müller) but the cross-cups are more bluntly rounded, almost identical with those of *P. coriacea* (Hutton) from New Zealand.

Type. — M. C. Z.

Type locality. — Marco, Florida.

Distribution. — Known from the Gulf of Mexico, coast of Florida and Texas, possibly more widely distributed in the Gulf of Mexico.

Depth. — Shallow water.

Specimens examined. — Several in the M. C. Z.

Remarks. — The question of the varieties of *P. chilensis* has recently been discussed by Deichmann (1938), who found that *P. chilensis* ranges from Chile to the Japanese waters and recently has been found in the Bay or Monterey, California, and also off the west coast of Mexico and Guatemala and Costa Rica. The specimens from the last mentioned locality came from relatively deep water, 35-40 fathoms and the spicules were somewhat untypical while the Mexican and Guatemalan specimens from 7 and 10 meters depth had spicules which partly resembled the typical *chilensis* spicules, partly those of the New Zealand and the West Indian species. It seems as if the spicules have a tendency to develop blunt spines in the individuals from the northern and southern waters while the eastern and western forms tend to develop rounded disks, and both types are combined in the individuals from the western coast of Central America. To maintain *P. obesacauda* as a separate species is mostly a practical way of indicating its geographical range.

3. Hedingia Deichmann, 1938

Hedingia Deichmann, 1938, p. 112.

Synonym. *Caudina auctores* (partim). *Trochostoma* auctores (partim). Nec *Trochostoma* Danielssen & Koren (i. e. *Molpadia* Cuvier).

Diagnosis. — Medium-sized caudinids, usually with long, narrow tail end. Skin thin, rigid, filled with large spicules. Inner anatomy

similar to that of *Caudina* but no lateral pseudo-mesenteries attached to the third loop of the intestine.(*)

Spicules, large tables with numerous holes in the disk and three-pillared spire or reduced to a cluster of spines or totally lacking; spicules often spinous. Deep water forms.

Type species. — *Hedingia albicans* (Théel).

Remarks. — A list of the four species referred to the genus is found in Deichmann, 1938, p. 112. Three of the species are known from the eastern and northern Pacific, while the type species is found in deep water in the Atlantic Ocean and also reported from near New Zealand.

Hedingia albicans (Théel)

Trochostoma albicans Théel, 1886.
Caudina arenata Gould var. *armata* Théel, 1886 a, p. 17. Nec *Caudina arenata* Gould.
Caudina albicans H. L. Clark, 1908, p. 37.
Trochostoma mediterranea Baldelli-Bartolini, p. 105.
Haplodactyla albicans Heding, 1935, p. 65, pl. 4, fig. 9, pl. 5, fig.
Hedingia albicans Deichmann 1938, p. 112.

Diagnosis. — As for the genus. Spicules large tables with numerous holes in the disk which often is triangular in outline; spire, three-pillared; disk and spire often spinous.

Type. — British Museum.

Type locality. — Off New England, 38° 34′ N., 72° 10′ W., 1,240 fathoms.

Distribution. — Eastern and Western Atlantic, Mediterranean. A variety, var. *glabra* Théel, known from off New Zealand.

Depth. — About 900-1,500 fathoms.

Specimens examined. — The following material from the "Atlantis" summer cruises during 1937, 1938 and 1939.

(*) Hedig finds strands attached to the third loop of the intestine beside the ventral mesentery. The material I have had occasion to examine was not very well preserved. About this structure which is so well marked in *Caudina* and *Paracaudina*. Oestergren (1907, p. 210, footnote) emphasizes how "Bei *Caudina arenata* (Gould) finden sich ähnliche wenn auch schwachere Pseudomesenterien (he is discussing *Caudina arenicola* Stimpson) bei der nachverwandten (artlich doch scheidenden) *C. armata* (Théel) (i. e. *Hedingia albicans* Théel) fehlen diese Bildungen jedoch was ihre geringe systematische Bedeutung beweist."

			Fathoms		
1937, August 10,	38° 31′ N.,	73° 03′ W.,	975- 905	1	specimen
1938, August 3,	37° 43′ N.,	73° 40′ W.,	1,105	1	fragment (tail end)
1938, August 4,	38° 58′ N.,	72° 19′ W.,	1,040	1	specimen
1938, August 4,	38° 59′ N.,	72° 20′ W.,	980	1	„
1939, July 24, Tow 4,	40° 05′ N.,	67° 52′ W.,	1,325	1	„
1939, July 26, Tow 6,	40° 05′ N.,	68° 05′ W.,	1,105-1,135	1	„
1939, July 26, Tow 7,	40° 06′ N.,	68° 06′ W.,	1,160-1,100	1	„

Remarks. — The specimens agree well with Théel's description which was based on one individual from the same weters. The tables show a varying amount of spines. The species is most closely related to *H. ludwigi* Ohshima from Japanese waters.

3. MOLPADIIDAE

Diagnosis. — Typical Molpadonia with 10-15 small tentacles in a circles, claw-shaped or with terminal digit and a few small lateral digits. Calcareous ring with short posterior prolongations on the radials. Tentacle ampullae usually well developed (in one species almost lacking). Stone canal attached to integument behind the opening for the gonads in the dorsal midline. Other anatomical features typical.

Spicules tables, three-pillared or with spire fused into a single spine; in some forms the spire is reduced in most tables so they form large plates; sometimes fusiform rods are present. Tail with tables, often smaller, often with elongate disk, in some forms modified into long fusiform rods with or without a spire. Phosphatic bodies present ih some species, increasing in number with advancing age; in some cases the calcareous spicules are resorbed at the same time; in other forms phosphatic bodies seem to be totally lacking. Anchors and racquet-shaped plates are present in some forms, either during the early stages or throughout life; in others they seem to be totally lacking.

KEY TO THE GENERA NOW ACCEPTED

Tentacles fifteen in number, soft, with terminal and lateral digits. . . . . [*Ceraplectana* H. L. Clark]
Tentacles ten in number, hard, claw-shaped. . . . *Molpadia* Cuvier

Remarks. — The genus *Molapdia* has seven valid representatives in the western part of the Atlantic Ocean and five of these appear to be restricted to the American waters. An eighth species is known from the Eastern Atlantic and a ninth and tenth from the northern Atlantic and the Arctic Sea. (See list on p. 00). *Ceraplectana* with one species, is known from the Northern and Eastern Pacific only.

Ankyroderma and *Trochostoma*, both of Danielssen & Koren, represent in my opinion, merely juvenile and senescent stages of *Molpadia*. *Haplodactyla* Grube, 1840 and Heding, 1931 is a complete synonym of *Molpadia*, based on material of *M. musculus* (Risso) while *Haplodactyla* Heding, 1935 is a synonym of that part of *Caudina* now called *Hedingia*. *Embolus* Selenka, 1867 was based on poor material of *Molpadia oolitica* (Pourtalès) and is simply a synonym of *Molpadia*.

Pseudomolpadia, *Paratrochostoma* and subgenus *Paramolpadia*, all of Heding, 1931, must likewise be withdrawn as synonyms of *Molpadia*. (See Deichmann, 1936).

KEY TO THE SPECIES MOLPADIA KNOWN FROM THE WESTERN PART OF THE ATLANTIC OCEAN

1. Spicules chiefly three-pillared tables with several cross beams (in one species normally reduced with advancing age, in another partly substituted by huge plates). Tail with tables of roundish or elongate outline but not typically fusiform in shape.	2
1. Spicules chiefly one-pillared tables without any trace of cross-beams, may partly become substituted by large plates in certain species. Tail with fusiform rods.	5
2. Phosphatic bodies seems to be totally lacking; tables large; besides also enormous perforated plates; tail with oblong tables.	3. *Molpadia barbouri* spec. nov.
2. Phosphatic bodies present. Tables not remarkably large; no perforated plates present.	3
3. Tables mostly with irregular, disk with 3-12 holes, edge often incompletely closed; tail with irregular tables with tendency to develop an oblong disk. Spicules often almost completely lacking in larger individuals which may be nearly black from the numerous phosphatic bodies.	1. *Molpadia oolitica* (Pourtalès)
3. Tables fairly regular disk, with 3-6 holes; edge complete.	4
4. Tail with smaller tables with rounded or oblong outline of the disk and numerous small holes; phosphatic bodies present but not excessively numerous.	2. *Molpadia cubana* spec. nov.
4. Tail with oblong tables with few holes. . .	5. *Molpadia parva* (Théel)

5. Spicules mostly large plates; if spire is present it is one-pillared. Tail with large fusiform rods; no phosphatic bodies. . . . 4. *Molpadia agassizi* (Théel)

5. Spicules small to moderately sized tables with 3-6 holes, in one species gradually substituted by large fusiform rods or rhombic plates. 6

6. Spicules small tables with 3, rarely 6 holes; spire tapering or ending in hooks; no phosphatic bodies. Tentacle ampullae unusually short, almost lacking. . . . . 6. *Molpadia blakei* (Théel)

6. Spicules in body wall of varying size with 3-6 holes, often disk with marginal projections; in older individual the tables are replaced by fusiform rods or rhombic plates; phosphatic bodies numerous. . . . . 7. *Molpadia musculus* (Risso)

1. Molpadia oolitica (Pourtalès)

(Plate 36, figs. 1-3)

Chiridota oolitica Pourtalès, 1851, p. 13.
Molpadia oolitica Deichmann, 1936, p. 58, text figs. (List of the more important references.
Trochostoma turgida Verrill, 1879, p. 462, 1885, p. 539.
Molpadia turgida H. L. Clark, 1908, p. 104. Deichmann, 1930, p. 195, pl. 22, figs. 1-3, 14-180.

Diagnosis. — Large form (up to 15 cm. long); external and internal anatomy quite typical.

Spicules normally reduced with age, sometimes retained, often present only in the tail region. Spicules three-pillared tables with 3-12 holes, disk often irregular, with marginal projections or imperfectly closed holes. Tables in tail of similar size, often with two terminal projections. Phosphatic bodies numerous, especially in older individual which may almost black from them. Anchors and racquet-shaped plates apparently never present.

Type. — M. C. Z.

Type locality. — Massachusetts Bay, from stomach of cod.

Distribution. — Common off the coast of New England, not north of New Foundland. Reported from Charleston (*M. pauper* (Selenka) and off Florida (*M. borealis* Pourtalès) but may not be a normal element of that region (wrong locality?).

Depth. — Between 50-400 fathoms.

Specimens examined. — The type and several older specimens in the M. C. Z. A large individual from (Atlantis, 1935) with its

spicules retained, and 34 small individuals from off Gloucester, 70 fms. (collected by J. Miller, spring 1939) likewise with well developed spicules.

Remarks. — The discovery of numerous small individuals of *M. oolitica* within the area where it normally occurs is of interest. It has permitted comparison with the form from off Cuba, hitherto considered the young of *oolitica* but now accepted as a distinct species and it has definitely solved the mystery of Verrill's *M. turgida* from the New England waters.

Verrill's species has long been suspected of being a synonym of *M. oolitica* but the almost total lack of spicules in most individuals of the latter made it almost impossible to make use of Verrill's definition. Furthermore a curious error appeared in H. L. Clark's account 1908, p. 158, namely the statement that *turgida* had 12-40 perforations in the disk of the tables and this error was repeated by Deichmann in 1930. An extract of Verrill's description indicates that *turgida* reaches a size of 12.5 cm. and the spicules contains tables with three inner holes and an external circle of smaller holes ten or more; edge often with irregular projections. Spine elongate, acute, consisting of three or four colums; numerous phosphatic bodies. In other words *turgida* represents individuals of *oolitica* in which the spicules are preserved. Verrill states the species occurs between 45-858 fathoms (1885); Deichmann has found the greatest depth for specimens of *oolitica* with exact locality to be about 400 fathoms. Possibly Verrill by mistake has included some records of *M. musculus* (Risso) which occurs in deeper water off the coast of New England.

2. **Molpadia cubana** spec. nov.

(Plate 37, figs. 1-3)

Trochostoma antarcticum Théel, 1886 a, p. 16. Nec *T. antarcticum* Théel, 1886.
Molpadia oolitica Deichmann, 1930, p. 195 (partim). Nec *M. oolitica* Pourtalès, 1857, p. 13.

Diagnosis. — Small form (up to 4 cm. long), with three-pillared tables with 3 larger and a varying number of smaller holes. Tail with much smaller tables with numerous holes, disk of tables round or oblong but without definite prolongations. Phosphatic bodies present, often in association with spicules; anchors and raquet-shaped plates never observed.

Type. — M. C. Z.
Type locality. — Off Havana, 175-210 fathoms.

Distributions. — Known only from the waters around Cuba.

Depth. — Normally between 150-285 fathoms. The depth of 1,440 fathoms (station 3,344) may be an error in labelling.

Specimens examined. — The types and the following individuals from the Atlantis cruises:

						Fathoms		
Station	2962D	22° 07′	N.,	81° 08′	W.,	175-210.	3	specimens. Types
„	2963A	22° 07′	N.,	81° 08′	W.,	155-190.	1	„
„	2963C	22° 07′	N.,	81° 08′	W.,	205.	1	„
„	2982D	22° 44′ 30″	N.,	73° 41′	W.,	150-180.	9	„
„	2982E	22° 45′	N.,	78° 46′	W.,	150-180.	10	„
„	3328	22° 08′	N.,	81° 10′	W.,	260-275.	2	„
„	3332	22° 09′ 30″	N.,	81° 11′	W.,	175-225.	2	„
„	3333	22° 13′	N.,	81° 11′	W.,	190-200.	5	„
„	3344	21° 38′	N.,	80° 12′	W.,	1,440.	1	„
„	3376	22° 44′ 30″	N.,	75° 18′	W.,	285.	1	„
„	3406	22° 42′	N.,	78° 38′	W.,	200.	1	„
„	3410	22° 47′	N.,	78° 41′	W.,	260.	1	„
„	3414	22° 30′ 30″	N.,	78° 52′	W.,	230.	10	„
„	3415	22° 51′ 30″	N.,	78° 35′ 30″	W.,	210.	1	„
„	3417	22° 50′	N.,	78° 56′	W.,	200.	2	„
„	3409	22° 44′	N.,	78° 41′	W.,	200.	1	„

Remarks. — The numerous individuals measure between 2-4 cm. in contracted condition; fully expanded they would probably measure around 5 cm. The color is white with more or less pronounced rusty tinge here and there in the places where the phosphactic bodies are numerous.

The inner anatomy is not remarkable in any ways except that the animals apparently are sexually ripe and the individuals collected therefore may represent the fulgrown stage of this species. The gonads in the Atlantis specimens, collected in the early spring, are partly collapsed tubes with swollen bead-like portions as if the sex-products necently had been shed.

M. cubana was in 1930 regarded as the juvenile stage of *M. oolitica* Pourtalès, the common form from off the coasts of New England and also supposedly recorded from the coast of Florida. The three small specimens from the Blake Expedition (identified as *antarctica* by Théel) were considered to represent the only juvenile stages of *M. oolitica* known in any collection. Fortunately a large number of small individuals of *M. oolitica* of about the same size (3-4 cm.) were dredged by Mr. J. Miller from Gloucester, 70 fms. and direct

comparison between the northern and southern form became therefore possible. The result was that the southern form was found to deserve to be considered as a separate species.

M. cubana differs from *oolitica* in the more trim and firmly built tables with rounded edges, and the much smaller tables in the tail which show no tendency to develop prolongations. Also it is, as far as our present knowledge goes, a much smaller species. From Théel's *M. antarctica* from off the coast of Chile it differs in the presence of phosphatic bodies and in apparently the general shape of the spicules. Direct comparison of the two species would, however, be highly desivable.

3. **Molpadia barbouri** spec. nov.

(Plate 39, figs. 1-6)

Diagnosis. — Medium-sized form (6-8 cm. long); skin rigid filled with numerous large spicules and rough to the touch on account of the large spires of the tables. Inner anatomy typical; calcareous ring with long posterior radial prolongations, slightly bifid; tentacle ampullae short, barely reaching the posterior margin of the calcareous ring; stonecanal long with a small rounded head attached in the dorsal mesentery next to the genital duct; a single ventral Polian vesicle is present; gonads as two tufts of short tubes; respiratory trees slender with short lateral lobes; musclebands divided.

Spicules large tables with large disk, mostly with four large central holes and a varying number of marginal holes; spire tall, with 3-4 pillars and a varying number of cross beams and spines. Also large plates, probably derived from tables. Tail with tables with oblong disk, approaching fusiform rods; spire often small or lacking. Phosphatic bodies as well as anchors and racquet-shaped bodies seem to be totally lacking (only fairly large individuals have been examined). Color in alcohol pure white.

Type. — M. C. Z.

Type locality.

Distribution. — The waters around Cuba.

Depth. — From 370-605 fathoms.

Specimens examined. — The following material from the "Atlantis" cruises.

					Fathoms			
Station	2994	23° 24′	N.,	80° 44′ W.,	580.	3	specimens	
„	2995	23° 24′	N.,	81° 00′ W.,	370-605.	6	„	
„	3313	22° 12′ 30″	N.,	85° 06′ W.,	550.	5	„	(including the type).

Remarks. — The 12 specimens measure between 3 cm. and 8 cm.; the smallest are unusually contracted so they actually represent much larger individuals. The species is striking with its white color and rigid, finely spinulose skin whith no trace of phosphatic bodies. It represents undoubtedly the counterpart to *Molpadia agassizi* Théel among the forms which have tables built up of 3-4 pillars while the latter typifies a deep water form of the group which has a spire composed of a single rod. It cannot be mistakern for any other species in the Atlantic Ocean.

4. Molpadia agassizi (Théel)

(Plate 39, Nos. 7, 8)

Ankyroderma agassizi Théel, 1886 a, p. 19.
Molpadia agassizi, H. L. Clark, 1908, p. 169. Deichmann, 1930, p. 197, pl. 23, figs. 1-3.

Diagnosis. — Medium sized forms (6-7 cm.), with thin, rigid integument, filled with large perforated plates and a few tables with solid spire. Tail with fusiform rods. No trace of phosphatic bodies but anchors and racquet-shaped plates are numerous in the types.

Type. — M. C. Z.

Type locality. — Off Bequia, from 2,712 meters depth.

Distribution. — West Indies.

Specimens examined. — The type and another individual from the "Blake" expedition but lacking locality.

Remarks. — The glassy integument and the lack of phosphactic bodies gives this species a certain resemblance to *M. barbouri* and the spicules are therefore here figured side by side to emphasize the differences.

5. Molpadia parva (Théel)

(Plate 38, Nos. 4-6; text figures 9, Nos. 1-3)

Trochostoma arcticum var. *parva* Théel, 1886 a, p. 17.
Trochostoma arcticum var. *coerulum* Théel, 1886 a, p. 17.
Molpadia parva H. L. Clark, 1908, p. 108. Deichmann, 1930, p. 196, pl. 22, figures 10-13.

Diagnosis. — Medium-sized form (up to 7 cm.); spicules medium-sized tables with three large central holes and normally three or more smaller marginal holes. Spire tall with three pillars and several cross-beams. Similar tables but with more or less oblong disk are present in the tail. Phosphatic bodies lacking or rare. Anchors and racquet-shaped plates discovered in one individual.

Types. — M. C. Z.

Type locality. — Off Grenada, 416 fathoms (var. *parva*) and 583 fathoms (var. *coerulum*).

Distribution. — Known from the typelocalities and south of Cuba. According to H. L. Clark also taken off Nantucket "Albatross" stations 2,144 and 2,106 (U. S. N. M.).

Depth. — From 416 to about 1,300 fathoms.

Specimens examined. — Théel's two types and the following material from the "Atlantis" cruises.

Station 3345 21° 08′ N., 79° 56′ 30″ W., 690-700 fathoms. 1 specimen

Remarks. — The "Atlantis" specimen resembles the type of var. *parva.* The spicules are of the same shape and the skin contains the diffuse pigment which also characterizes the type. A few red phosphactic bodies were discovered in the skin of the type specimen. More interesting was, however the discovery that a few anchor's and racquet-shaped plates were present in the "Atlantis" specimen.

As the spicules of neither var. *parvum* nor var. *coerulum* were figured by Théel in 1886 they are now figured. The tables of var. *coerulum* are somewhat more complex but until more material is available it seems natural to regard to two forms as identical.

6. Molpadia blakei (Théel)

(Plate 38, Nos. 6-8)

Trochostoma blakei Théel, 1886 a, p. 16, pl. 1, fig. 8. Perrier, 1902, p. 525, pl. 22, figs. 3-6.
Molpadia blakei, H. L. Clark, 1908, p. 163. Deichmann, 1930, p. 196, pl. 22.
Trochostoma blakei var. *excentrica* Hérouard, 1923, p. 136, pl. 9, figs. 3-9.
Trochostoma angulatus Hérouard, 1923, p. 136, pl. 3, fig. 6, pl. 8, fig. 3.
Trochostoma grossularia Hérouard, 1923, p. 137, pl. 9, figs. 13-16, 21-32..
Paratrochostoma spiniferum Heding, 1935, p. 72, pl. 4, figs. 13-14, pl. 5, figures 20-21.

Diagnosis. — Medium-sized form (6 cm.); tentacle ampullae unusually short almost lacking.

Spicules in body wall minute tables with three large holes in the disk and a solid spire tapering into a point or ending in a few hook; base of spire often divided into three pillars. Tail with fusiform rods or tables with a low spire ending in a few hooks. No phosphatic bodies, anchors or racquet shaped plates.

Type. — M. C. Z.

Type locality. — Off Grenada, 945 fathoms depth.

Distribution. — West Indies, off Nova Scotia (*T. angulatum* Hérouard) and Eastern Atlantic (*T. grossularia* var. *excentrica* Hérouard). Recently reported from the waters south and west of Greenland (i. e. *Paratrochostoma spiniferum* Heding).

Depth. — From about 1,000 to 1,500 fathoms.

Specimens examined. — The type in the M. C. Z. and some individuals in the U. S. N. M.

Remarks. — An excellent description has been given by Heding who finally points out that *Parathochostoma spiniferum* possibly is identical with *M. blakei* or its varieties. The excentric position of the tail which Hérouard noticed in his variety *excentrica* is, however, not a stable character as it may occur in some individuals of any species of *Molpadia* an not in others, taken in the same haul. The shape of the calcareous ring falls likewise within the range of variation which is considerable the genus *Molpadia.* The most significant character which Heding indicates, namely the lack of free tentacle ampullae is the only one which possibly justifies a new genus although not transference of the genus to the *Eupyrgidae.* Actually the tentacle ampullae are merely unusually short and may in some specimens appear to be totally lacking while they are perfectly distinct in other individuals. The undivided musclebands which Heding claims are present in his small specimens of *P. spiniferum* are not characteristic of Théel's type which has very wide bands, distinctly divided, as in the other members of the genus *Molpadia.* It seems there fore more correct to withdraw the genus *Paratrochostoma* as a synonym of *Molpadia* and modify the diagnosis of the latter to read "tentacle ampullae present but in some forms notably short".

7. Molpadia musculus (Risso)

(Plate 40, Nos. 1-15)

Molpadia musculus H. L. Clark, 1908, p. 165, pl. 23, figs. 4-7 (complete list of references). Deichmann, 1930, p. 198, pl. 22, figs. 4-9, pl. 23, figs. 4-7.

Ankyroderma loricata Perrier, 1901, p. 535, pl. 22, figs. 23-28. Hérouard, 1923, p. 133.

Eumolpadia asaphes Heding, 1931, p. ...; 1935, p. 42, pl. 5, figs. 9-10, pl. 7, fig. 2, pl. 8, fig. 3, text fig. 9.

Diagnosis. — Large form (up to 16 cm.).

Spicules tables with solid spire, 3-6 holes in the disk, often marginal projections and, with advancing age, fusiform plates or rods, broad or narrow, with a varying number of holes, often an abortive spire. Tail with fusiform rods with 3-4 central holes, sometimes a

minute spire. Phosphatic bodies present in varying number; anchors and racquets present in most individual but may be completely reduced.

Type. — Undoubtedly lost.

Type locality. — Mediterranean Sea, probably in less tan 200 fathoms depth.

Distribution. — Circumtropical, and reaching more northern and southern localities in certain places (North Atlantic (*M. asaphes* Heding) Kerguelen (*M. violacea* Studer, Théel). Also off New Zealand, off Chile, etc.

The following material from the "Atlantis" cruises.

Station	2962	22° 07′ N.,	81° 08′	W.,	200-210	fathoms.	2	specimens
„	2962D	22° 07′ N.,	81° 08′	W.,	175-210	„	1	„
„	2963C	22° 07′ N.,	81° 08′	W.,	205	„	6	„
„	3328	22° 08′ N.,	81° 10′	W.,	260-275	„	10	„
„	3345	21° 08′ N.,	79° 56′ 30″	W.,	690-700	„	1	„
„	3374	20° 45′ N.,	75° 19′	W.,	300	„	1	„
„	3387	22° 33′ N.,	78° 10′	W.,	245	„	1	„
1938, Aug.	3	37° 43′ N.,	73° 40′	W.,	1,105	„	1	„

Remarks. — The majority of the specimens from the Western Atlantic agree well with the typical form, described from the Mediterranean, and cannot either be separated from specimens from the Eastern Pacific. The fusiform spicules in the bodywall (lacking in young individuals) show two extremes, the *loricata*-type, with broad rhombiform plates, and the *violacea*-type, with narrow needle-like rods, usually with the central holes placed in a depression.

A series ranging from 1-6 cm. has been examined. In the smallest individuals only delicate tables are present; later heavier tables appear, often with marginal projections and finally typical fusiform plates or rods, or a mixture of both, become dominating.

Anchors and racquets are numerous in smaller individuals but become gradually more scarce and seem sometime to be totally lacking. Phosphatic bodies are present in varying numbers; most of the Atlantis specimens are slightly freckled or show rusty-red patches, other individuals are dark red in color.

The largest specimen from the northern waters measures 8 cm. in length and has narrow fusiform rods, numerous phosphatic bodies and lacks apparently totally anchors and racquets. It agrees therefore with Heding's *asaphes* based on a much smaller individual from the northern Atlantic or Studer's *violacea,* known from Kerguelen and

off the coast of Chile. There are, however, specimens in the M. C. Z. with exactly the same type of spicules, from the West Indian Seas and off the coast of Chile, and in these anchors and racquet are present, just as I have seen typical specimens of *M. musculus* with few or no anchors and racquets. I an therefore convinced that *asaphes* and *violacea* merely represent variations of *M. musculus* and not distinct species.

EUPYRGIDAE Semper, 1868

Eupyrgidae Semper, 1868, p. 24. Heding, 1931, p. 281; 1935, p. 68.

Diagnosis. — Small forms with 15 tentacles, apparently simple finger-shaped. Calcareous ring low without posterior prolongations; tentacle ampullae reduced; muscleband undivided; stonecanal attached to dorsal integument and opening to the exterior in front of the genital opening.

Spicules huge tables with numerous holes in the disk and three-pillared spire. Arct and subarctic forms.

Remarks. — The family comprises one genus, *Eupyrgus* Lütken, 1857. The other genus referred to the family, *Paratrochostoma* Heding, with one species *P. spiniferum* Heding, is a synonym of *Molpadia* and the type species is identical with *M. blakei* (Théel). Except for the unusually short tentacle ampullae it differs little from the typical members of the genus *Molpadia* and the stone canal opens behind the genital opening as in that genus, not in front of it as in *Eupyrgus*. The musclebands are divided while Heding claims they are undivided in his very small specimens of *P. spiniferum*. It is, however, often difficult to ascertain whether the bands are divided or simple in such small individuals, especially if they are strongly contracted.

EUPYRGUS Lütken, 1857

Diagnosis. — As for the family.

Type species. — *Eupyrgus scaber* Lütken.

Remarks. — The type species occurs widespread in the Arctic Seas, usually in comparatively shallow water. A related form, *E. pacificus* has been described by Oestergren from the Northern Pacific Ocean. An excellent anatomical description has recently been given of the type species by Heding, 1935, p. 69, pl. 4, figs. 10-11, pl. 8, fig. 11.]

ORDER V — APODA BRANDT

The "Atlantis" cruises around Cuba in the spring of 1938 and 1939 secured only one species, viz., the common large shore form, *Euapta lappa* (Müller). From more northern water were secured two deep water forms which are discussed below and furthermore is included a discussion of Verrill's *Toxodora ferruginea* which now is referred to the genus *Chiridota*.

For information about the West Indian apodous holothurians the reader is referred to Clark's and Deichmann's papers from 1908 and 1930 and various publications by Heding which have appeared since 1928.

FAMILY SYNAPTIDAE

Genus EUAPTA Oestergren

For diagnosis, etc., see Clark, 1908, pp. 70-73 and Deichmann, 1930, p. 205.

Synapta lappa J. Müller, 1850, p. 134. Théel, 1886, p. 10, pl. 1, fig. 7.
Euapta lappa H. L. Clark, 1908, p. 73, pl. 4, figs. 23-25. Deichmann, 1930, p. 205; 1936, p. 9.
Nec *Euapta lappa* Boone, 1928, p. 14, i. e. *E. godeffroyi* (Semper).

Specimens examined. — Several fragments from the following shore-locality of the "Atlantis" cruises.

Station 3347 April 9 20° 03′ N., 77° 55′ W., 13 fathoms. Fragments

Remarks. — The species occurs widespread in the West Indies. It has once been reported from Bermuda (H. L. Clark, 1907), overlooked by Deichmann (1930), but seems not to be a typical element of the islands fauna. According to Théel (1886) it is also known from Teneriffa.

A closely related form occurs in the Indo Pacific, ranging from Mauritius to the western coast of Mexico. In the latter locality it was described as *E. lappa* by Boone (1933) but later referred to *E. godeffroyi* (Semper) by Deichmann (1936). The two species differ in minor characters. Frequent malformation of the anchors and the presence of a webbing between the basal part of the tentacles are characteristic features of the Indo Pacific species. Comparison of a large number of well preserved specimens may possibly reveal

that the two species cannot be kept separate, in that case the name *E. lappa* must be retained as it is 18 years older than Semper's name.

PROTANKYRA Oestergren, 1898

For diagnosis, etc., see Clark, 1908, p. 103.

PROTANKYRA BRYCHIA (Verrill)
(Plate 41, Nos. 1-3)

Synapta brychia Verrill, 1885, p. 339.
Protankyra brychia Oestergren, 1898, p. 116. H. L. Clark, 1908, pp. 25, 103, pl. 4, figs. 12-14. Deichmann, 1930, p. 209. Ludwig (†) & Heding, 1935, p. 149 (passim).
Synapta sp. Théel, 1886 a, p. 20.

Diagnosis. — Medium-sized form (up to 10 cm. long, almost 1 cm. in diameter); tentacles unknown; Polian vesicles 2 in number (?) (or more).

Spicules anchors with smooth to serrate flukes and branched handle and deep scoop-shaped anchor-plates witn numerous holes with smooth or spinous edges; handle variously developed often as an irregular mass of branches. Miliary grains present along the ambulacra in the muscles. Color grayish with a purplish tinge.

Type. — U. S. N. M.

Type locality. — Off Cape Hatteras, 938 fathoms (headless fragments).

Distribution. — From the West Indies to off New York.

Depth. — From 938 to 1,105 fathoms.

Specimens examined. — The types in U. S. N. M.; a fragment from off Florida; Théel's fragment of *Synapta* sp. from off New Jersey, and some fragments from off New York (37° 43′ N, 73° 30′ W., 1,105 fms., "Atlantis", W. E. Schevill coll).

Remarks. — From the western part of the Atlantic Ocean two species have been reported, viz., *P. brychia* (Verrill) and *P. abyssicola* (Théel), the latter being originally described from the Eastern Atlantic. Heding has recently (Ludwig (†) and Heding, 1935) tried to outline the differences between the two Atlantic species. Nothing is, however, known about the arrangement of the ciliated funnels in Verrill's species, and Clark's statement that the species possesses two Polian vesicles may be erroneous since the type specimens which he examined lacked the oral end. The spicules of the types show considerable variation in size and intergrade with those of *P. abyssicola*. The anchors have, as usual, sometimes smooth, sometimes errate

flukes and the anchor-plates are oval to round with larger or smaller holes with smooth or dentate margin. They resemble Heding's figures, *P. abyssicola* from the Eastern Atlantic.(*) The latter species has 5-7 Polian vesicles and scattered ciliated funnels. I am convinced that Verrill's species includes also *P. abyssicola* (Théel). Ludwig's species *P. pacifica* (originally described as a variety of the Atlantic form) has, according to Heding, up to 10 Polian vesicles and ciliated funnels in longitudinal series—characters of rather dubious value—and more strongly spinulated anchor-plates. The anchors may, however, have smooth or serrate flukes according to their age, as Clark has pointed out in 1920. On acount of the definite difference in the spicules it seems corret to maintain *P. pacifica* as a distinct form. Apparently there is a tendency among the deep water forms to develop spines in the Pacific Ocean, as examplified by *Hedingia albicans* (Théel) and *Staurocucumis abyssorum* (Ludwig)(**) which have strongly spinous spicules in the Eastern Pacific Ocean while the representatives in the Atlantic Ocean have almost smooth spicules.

CHIRIDOTIDAE

CHIRIDOTA Eschscholtz 1829

Chiridota abyssicola v. Marenzeller, 1893, p. 19, p. 1, fig. 5, pl. 2, fig. 7. H. L. Clark, 1908, p. 119 (passim).

?Achiridota ingolfi Heding, 1935, p. 17.

?Paradota ingolfi Ludwig(†) and Heding, 1935, p. 150.

Diagnosis. — Medium-sized form (known to reach a length of 10 cm) with 12 tentacles with up to 15 digits (1 terminal and up to 7 on each side). Stone canal short, polian vesicles numerous (12-20).

Spicules in few wheel-papillae, possibly reduced in some individuals. Wheels with six spokes (diameter 0.08-0.1 mm.).

(*) Miliary grains occur, according to Heding, in the longitudinal muscles of *P. abyssicola* (they were not mentioned by Théel) and Ludwig found them likewise in *pacifica*. H. L. Clark observed that there was miliary grains along the radii in the types of *brychia* and used that character to distinguish the latter from *abyssicola* and *pacifica* but, by an error, he states (p. 103) that *brychia* lacks accessory grains. He figures, nowever, the grains (pl. 4, fig. 14) and they agree completely with Hedings figures. As they are present in all three "species" they are of no value as a distinguishing character.

(**) In case of *S. abyssorum* the corresponding Atlantic form has been considered a distinct species, *S. ingolfi* (Deichmann). See Mortensen, 1927.

Type. — Monaco.

Type locality. — Off the Azores.

Distribution. —Eastern and Western Atlantic.

Depth.

Specimens examined. — A fragment from one of the "Atlantis" cruises off New York (with *P. brychia* (Verrill)), Aug. 4, 1938, 38° 58′ N., 72° 19′ W., 1,040 fathoms.

Remarks. — The records of a species of *Chiridota*, closely allied to *C. laevis* (Fabricius) but from deep water, has always been viewed with suspicion. As the "Atlantis" operated solely in deeper water in August 1938, and the *Chiridota* furthermore was in a vial which contained *Protankyra brychia* it seems proved beyond doubt that the specimen actually came from deeper water.

From v. Marenzeller's description may be quoted that the type of *C. abyssicola* measured 10 cm. in length and had 12 tentacles with 12-15 digits; the gonads on the right side of the mesentery were considerably larger than those on the left side. The wheel-papillae were few, only 4 in number each contained about 20 wheels with six spokes and ranging in size from 0.08-0.1 mm. in diameter. No other spicules were described but probably it did not occur to v. Marenzeller to examine the tentacles and the skin immediately behind these. Very likely they would have been found to contain rods of similar type as those present in the tentacles of *C. leavis*.

The "Atlantis" fragment represents a hind-end with a few wheels, sufficient to establish the generic position of the animal and nothing seems to speak against referring it to v. Marenzeller's species.

As the wheel-papillae are few in this species and as it is known that the wheels often become completely reduced in certain deep water forms of *Chiridota* known from the Pacific Ocean, it seems quite probable that *Paradota abyssicola* Heding, from deeper water in the Eastern Atlantic, may represent a specimen of *C. abyssicola* v. Marenzeller in which the wheels have disappeared. Heding's specimens were smaller; the tentacles were 12 in number(*) and had only 7-9 digits; the stone canal had a cylindrical head about 12 Polian vesicles were present. Spicules were lacking except for a few rods in the tentacles and in the skin behind these. Heding's individuals came from 1,750 and 2,258 meters depth, while v. Marenzeller's specimen came from 2,870 m. and the "Atlantis" specimen was taken at 1,105 fathoms depth.

(*) By mistake the number is given as 15 in the diagnosis.

Chiridota ferruginea (Verrill)

(Plate 41, figs. 4-7)

Toxodora ferruginea Verrill, 1882, p. 220. H. L. Clark, 1908, p. 126. Deichmann, 1930, p. 213. Ludwig (†) and Heding, 1935, p. 150 (passim).

Diagnosis. — Medium-sized form (less than 10 cm.); tentacles 12, with numerous digits; skin translucent, filled with minute reddish pigment spots.

Spicules numerous curved rods and sometimes a few six-spoked wheels, probably normally in wheel-heaps.

Type. — Possibly in U. S. N. M.

Type locality. — Eastern coast of the United States (Albatross sta. 870).

Distribution. — Known from the type locality and vicinity.

Depth. — From 71-155 fathoms.

Specimens examined. — Two head-less fragments in the M. C. Z., part of Verrill's material.

Remarks. — The material of *Toxodora ferruginea* Verrill in the M. C. Z. was re-examined in connection with the study of the deep water *Chiridota* discussed above. It was then discovered that in this species which supposedly lacked these structures, a few wheels actually were lying in the skin. As the absence of wheels was the sole reason for maintaining the genus *Toxodora* the latter must therefore be withdrawn, as a synonym of *Chiridota*.

Chiridota ferruginea is undoubtedly closely related to *C. albatrossi* Edwards from the western coast of North America. The latter species has likewise scattered rods in the skin and shows tendency to loose its wheels; it is also found in deeper water.

Heding's suggestion that *Paradota* possibly is a synonym of *Toxodora* cannot be upheld except so far as *Paradota* possibly also may be discovered to possess wheels and thus likewise becomes a synonym of *Chiridota*.

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LIST OF STATIONS WHERE HOLOTHURIANS WERE SECURED

2960	22° 07′	N., 81° 08′ 30″ W.,	270 fathoms. Near Bahia de Cochinos, Santa Clara, Cuba. February 18, 1938. *Sphaerothuria asperrima* (Théel).
2961	22° 07′	N., 81° 08′ 30″ W.,	250-255 fathoms. Near Bahia de Cochinos, Santa Clara, Cuba. February 23, 1938. *Holothuria lentiginosa* v. Marenzeller.
2962	22° 07′	N., 81° 08′ W.,	200-210 fathoms. Near Bahia de Cochinos, Santa Clara, Cuba. February 24, 1938. *Sphaerothuria asperrima* (Théel). *Molpadia musculus* (Risso).
2962C	22° 07′	N., 81° 08′ W.,	210 fathoms. February 24, 1938. Near Bahia de Cochinos, Santa Clara, Cuba. February 24, 1938. *Sphaerothuria asperrima* (Théel).
2962D	22° 07′	N., 81° 08′ W.,	175-210 fathoms. February 24, 1938. Near Bahia de Cochinos, Santa Clara, Cuba. *Molpadia cubana* n. sp. *Molpadia musculus* (Risso).
2963A	22° 07′	N., 81° 08′ W.,	155-190 fathoms. Near Bahia de Cochinos, Santa Clara, Cuba. February 25, 1938. *Molpadia cubana* n. sp.

2963C	22° 07′	N., 81° 08′	W., 205 fms. Near Bahia de Cochinos, Santa Clara, Cuba. February 25, 1938. *Molpadia cubana* n. sp. *Molpadia musculus* (Risso).
2963E	22° 07′	N., 81° 08′	W., 220-235 fathoms. Near Bahia de Cochinos, Santa Clara, Cuba. February 25, 1938. *Bathyplotes bigelowi* n. sp.
2966	20° 47′	N., 80° 24′	W., 2,125 fathoms. South of Santa Clara Province, Cuba. February 26, 1938. *Benthodytes typica* Théel. *Euphronides kerhervei* (Hérouard).
2967	19° 47′	N., 75° 06′	W., 1,530 fathoms. Off Bahia de Guantanamo, Oriente, Cuba. March 4, 1938. *Benthodytes typica* Théel.
2967A	19° 47′	N., 75° 06′	W., 1,580-1,800 fathoms. Off Bahia de Guantanamo, Oriente, Cuba. March 4, 1938. *Benthodytes typica* Théel.
2967B	19° 45′ 30″	N., 74° 57′ 30″	W., 1,330-1,650 fathoms. SE of Bahia de Guantanamo, Oriente, Cuba. March 4, 1938. *Benthodytes typica* Théel.
2969	19° 47′	N., 75° 54′	W., 1,145-1,075 fathoms. EE of Bahia de Guantanamo, Oriente, Cuba. March 5, 1938. *Benthodytes lingua* Perrier.
2973	21° 09′	N., 75° 04′ 30″	W., 1,245-1,335 fathoms. N. of Oriente, Cuba. March 5, 1938. *Synallactes crucifera* Perrier.
2976	21° 19′	N., 76° 05′	W., 1,450 fathoms. N. of Gibara, Oriente, Cuba. March 8, 1938. *Benthodytes typica* Théel.
2982D	22° 44′ 30″	N., 78° 41′	W., 150-180 fathoms. Old Bahamas Channel due N. of Punta Caldera, Camagüey, Cuba. March 11, 1938. *Sphaerothuria asperrima* (Théel). *Molpadia cubana* n. sp.
2982E	22° 45′	N., 78° 46′	W., 150-180 fathoms. Old Bahamas Channel due N. of Punta Alégre, Camagüey, Cuba. March 11, 1938. *Molpadia cubana* n. sp.
2987	23° 22′	N., 79° 53′	W., 280-300 fathoms. Nicholas channel, S. of Cay Sol Bank, Cuba. March 13, 1938. *Bathyplotes bigelowi* n. sp.
2993	23° 24′	N., 80° 44′	W., 580 fathoms. N. of Bahia de Santa Clara, Santa Clara, Cuba. March 15, 1938. *Zygothuria lactea* (Théel).
2994	23° 24′	N., 80° 50′	W., 565-585 fathoms. N. of Bahia de Sta. Clara, Santa Clara, Cuba. March 15, 1938. *Molpadia barbouri* n. sp.

2995 23° 24′ N., 81° 00′ 30″ W., 370-605 fathoms. Off Bahia Cardenas, Matanzas, Cuba. March 16, 1938.
Molpadia barbouri n. sp.

3313 22° 12′ 30″ N., 85° 06′ W., 550 fathoms. Off Cape San Antonio, Pinar del Río, Cuba.
Molpadia barbouri n. sp.

3323 22° 00′ N., 81° 09′ 30″ W., 290-320 fathoms. Near Bahia Cochinous, Santa Clara, Cuba. April 4, 1939.
Bathyplotes bigelowi n. sp. TYPE.

3324 22° 08′ N., 81° 09′ 30″ W., 320 fathoms. Near Bahia Cochinos, Santa Clara, Cuba. April 4, 1939.
Amphigymnas bahamensis Deichmann.

3328 22° 08′ N., 81° 10′ W., 260-275 fathoms. Off Bahia Cochinos, Sta. Clara, Cuba. April 5, 1939.
Bathyplotes bigelowi n. sp.
Sphaerothuria asperrima (Théel).
Molpadia cubana n. sp.
Molpadia musculus (Risso).

3330 22° 09′ 30″ N., 81° 10′ 30″ W., 280-263 fathoms. Near Bahia Cochinos, Santa Clara, Cuba. April 5, 1939.
Sphaerothuria asperrima (Théel).

3332 22° 09′ 30″ N., 81° 11′ W., 175-225 fathoms. Near Bahia Cochinos, Sta. Clara, Cuba. April 5, 1939.
Sphaerothuria asperrima (Théel).
Molpadia cubana n. sp.

3333 22° 13′ N., 81° 11′ W., 190-200 fathoms. Near Bahia Cochinos, Santa Clara, Cuba. April 6, 1939.
Molpadia cubana n. sp.

3344 21° 38′ N., 80° 12′ W., 1,440 fathoms. Off Cienfuegos, Sta. Clara, Cuba. April 8, 1939.
Benthodytes typica Théel.
Pseudostichopus occultatus v. Marenzeller.
Molpadia cubana n. sp.

3345 21° 08′ N., 79° 56′ 30″ W., 690-700 fathoms. Off Banco Paz, Santa Clara, Cuba. April 8, 1939.
Molpadia musculus (Risso).
Molpadia parva (Théel).

3347 20° 03′ N., 77° 55′ W., 13 fathoms. Off Cabo Cruz, Oriente, Cuba. April 9, 1939.
Euapta lappa (J. Müller).

3355 19° 50′ N., 75° 00′ W., 1,070-1,950 fathoms. Near Guantanamo Bay, Cuba.
Euphronides violacea Perrier.

3358 20° 40′ N., 74° 32′ W., 975 fathoms. Between Cuba and Clarion Bank. April 18, 1939.
Deima blakei Théel (with a parasitic gasteropod).

3359	20° 38′	N., 74° 32′	W., 1,000 fathoms. Off Baracoa, Oriente, Cuba. April 18, 1939. *Benthodytes typica* Théel. *Benthodytes lingua* Perrier. *Zygothuria lactea* (Théel). *Mesothuria verrilli* (Théel).
3362	20° 48′	N., 74° 30′	W., 1,020 fathoms. Off Baracoa, Oriente, Cuba. April 18-19, 1939. *Mesothuria maroccana* Perrier.
3365	20° 46′	N., 74° 59′	W., 600 fathoms. Off Punta Cabanas, Oriente, Cuba. *Orphnurgus asper* Théel.
3366	20° 46′	N., 74° 59′	W., 625 fathoms. Off Punta Cabanas, Oriente, Cuba. April 19, 1939. *Deima blakei* Théel. *Orphnurgus asper* Théel. *Bathyplotes pourtalesi* (Théel).
3367	20° 46′	N., 75° 02′	W., 640 fathoms. April 19, 1939. *Orphnurgus asper* Théel.
3369	20° 49′	N., 75° 98′	W., 600 fathoms. Off Punta Cabanas, Oriente, Cuba. April 20, 1939. *Deima blakei* Théel. *Orphnurgus asper* Théel.
3370	20° 47′	N., 75° 11′	W., 450 fathoms. Off Puerto Tanamo, Oriente, Cuba. April 20, 1939. *Bathyplotes pourtalesi* (Théel).
3374	20° 45′	N., 75° 09′	W., 300 fathoms. Off Puerto Tanamo, Oriente, Cuba. April 20, 1939. *Sphaerothuria asperrima* (Théel). *Molpadia musculus* (Risso).
3375	20° 45′	N., 75° 20′	W., 230 fathoms. Off Puerto Tanamo, Oriente, Cuba. April 20, 1939. *Holothuria occidentalis* Ludwig. *Sphaerothuria asperrima* (Théel).
3376	20° 44′ 30″	N., 75° 18′	W., 285 fathoms. Off Puerto Tanamo, Oriente, Cuba. April 20, 1939. *Sphaerothuria asperrima* (Théel). *Molpadia cubana* n. sp.
3379	21° 49′	N., 76° 43′	W., 910 fathoms. Off Puerto Manati, Oriente, Cuba. April 25, 1939. *Euphronides violacea* Perrier.
3387	22° 33′	N., 78° 10′	W., 245 fathoms. Off Cayo Romano, Camagüey, Cuba. April 27, 1939. *Molpadia musculus* (Risso).
3389	22° 32′	N., 78° 08′	W., 220 fathoms. Off Cayo Romano Camagüey, Cuba. April 27, 1939. *Holothuria occidentalis* Ludwig.

3406	22° 42′	N., 78° 38′	W., 200 fathoms. Off Cayo Caco, Camagüey, Cuba. April 29, 1939. *Molpadia cubana* n. sp.
3409	22° 44′	N., 78° 41′	W., 200 fathoms. Off Punta Alegre, Camagüey, Cuba. April 29, 1939. *Molpadia cubana* n. sp.
3410	22° 47′	N., 78° 41′	W., 260 fathoms. Off Punta Alegre, Camagüey, Cuba. April 29, 1939. *Molpadia cubana* n. sp.
3414	22° 30′ 30″	N., 78° 52′	W., 230 fathoms. Off Punta Alegre, Camagüey, Cuba. April 29, 1939. *Molpadia cubana* n. sp.
3415	22° 51′ 30″	N., 78° 35′ 30″	W., 210 fathoms. Off Punta Alegre, Camagüey, Cuba. April 29, 1939. *Molpadia cubana* n. sp.
3417	22° 50′	N., 78° 56′	W., 200 fathoms. Off Punta Alegre, Camagüey, Cuba. April 30, 1939. *Molpadia cubana* n. sp.
3419	22° 46′ 30″	N., 79° 00′	W., 180 fathoms. Off Punta Alegre, Camagüey, Cuba. April 30, 1939. *Holothuria occidentalis* Ludwig.
3420	22° 49′	N., 79° 04′	W., 190 fathoms. Off Punta Alegre, Camagüey, Cuba. April 30, 1939. *Holothuria occidentalis* Ludwig.
3432	23° 05′	N., 79° 29′	W., 250 fathoms. Off Caibarien, Santa Clara, Cuba. May 1, 1939. *Bathyplotes bigelowi* n. sp.
3434	23° 10′	N., 79° 35′	W., 260 fathoms. Off Caibarien, Santa Clara, Cuba. May 1, 1939. *Bathyplotes bigelowi* n. sp.
3436	23° 05′	N., 79° 28′	W., 255 fathoms. Off Caibarien, Santa Clara, Cuba. May 2, 1939. *Bathyplotes bigelowi* n. sp.
3459	23° 21′	N., 80° 36′	W., 500 fathoms. May 5, 1939. *Mesothuria gargantua* Deichmann. *Mesothuria maroccana* Deichmann.
3465	23° 09′	N., 81° 27′	W., 175 fms. Off Matanzas, Matanzas, Cuba. May 4, 1939. *Holothuria lentiginosa* v. Marenzeller.
3475	23° 18′	N., 80° 48′	W., 400 fathoms. Off Matanzas, Matanzas, Cuba. May 10, 1939.
3480	23° 10′	N., 81° 28′	W., 200 fathoms. Off Matanzas, Matanzas, Cuba. May 11, 1939. *Stichopus regalis* (Cuvier).

3483 23° 12′ N., 81° 23′ W., 285 fathoms. Off Matanzas, Matanzas, Cuba. May 11, 1939.
Bathyplotes bigelowi n. s.

3484 23° 12′ 30″ N., 81° 22′ W., 300 fathoms. Off Matanzas, Matanzas, Cuba. May 11, 1939.
Bathyplotes bigelowi n. sp.

Other "Atlantis" stations from the northern waters, from which Holothurians were secured

1937, August 10, 38° 31′ N., 73° 03′ W., 975-905 fathoms.
Hedingia albicans (Théel).

1938, August 3, 37° 43′ N., 73° 40′ W., 1,105 fathoms.
Molpadia musmulus (Risso).
Hedingia albicans (Théel.)

1938, August 4, 38° 58′ N., 72° 19′ W., 1,040 fathoms.
Chiridota abyssicola v. Marenzeller.
Hedingia albicans (Théel).

1938, August 4, 38° 59′ N., 72° 20′ W., 980 fathoms.
Hedingia albicans (Théel).

1938, August 4, 39° 00′ N., 72° 19′ W., 1,050 fathoms.
Zygothuria lactea (Théel).

1939, July 26, Tow 6. 40° 05′ N., 68° 05′ W.
1,105-1,135 fathoms.
Zygothuria lactea (Théel).
Sphaerothuria talismani (Perrier).
Hedingia albicans (Théel).

1939, July 24, Tow 4. 40° 05′ N., 67° 52′ W.
1,325 fathoms.
Hedingia albicans (Théel).

1939, July 26, Tow 7. 40° 06′ N., 68° 06′ W.
1,160-1,100 fathoms.
Protankyra brychia (Verrill).
Hedingia albicans (Théel).

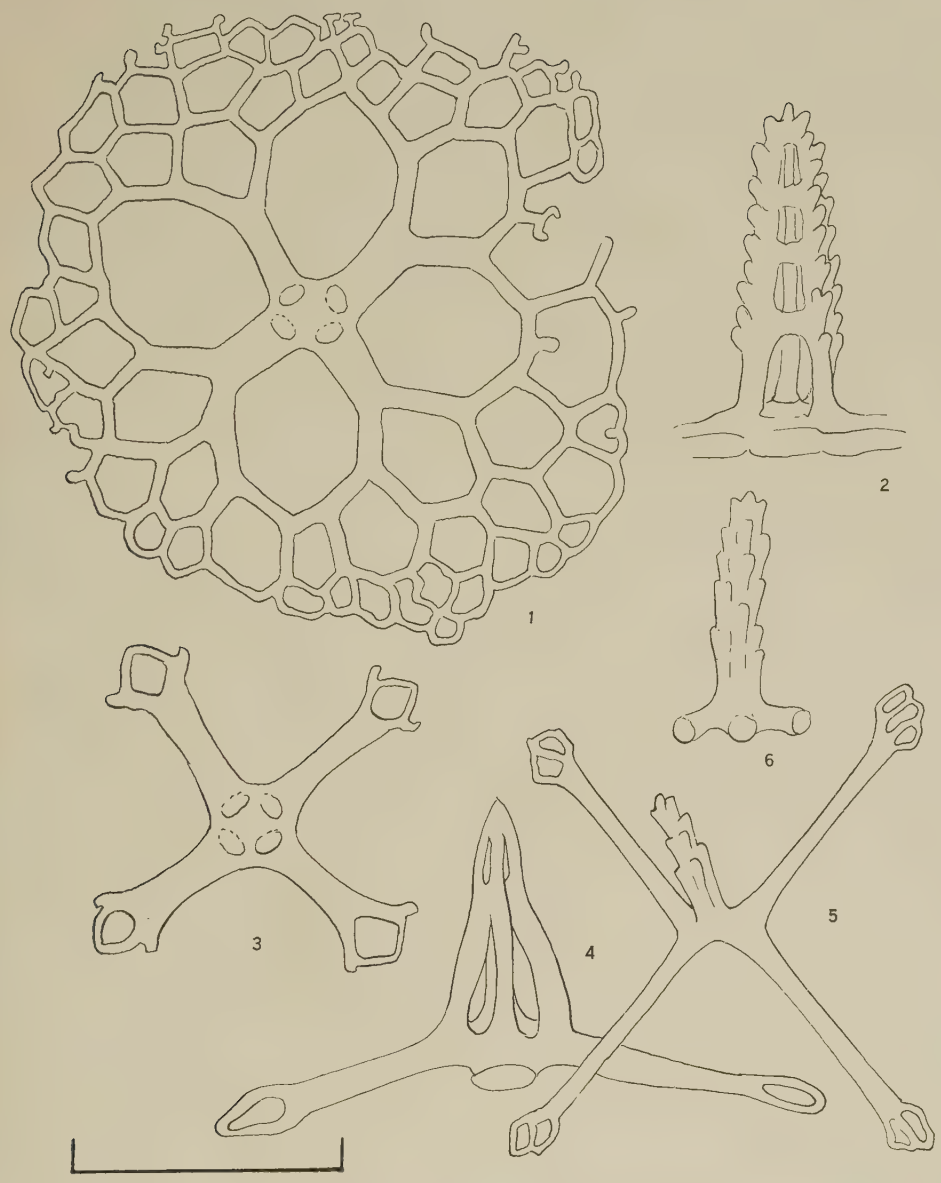
1939, July 27, Tow 8. 40° 01′ N., 68° 06′ W.
1,230 fathoms.
Psolus pourtalesi (Théel).

1939, July 27, Tow 9. 39° 09′ N., 68° 05′ W.
1,280 fathoms.
Psolus pourtalesi (Théel).

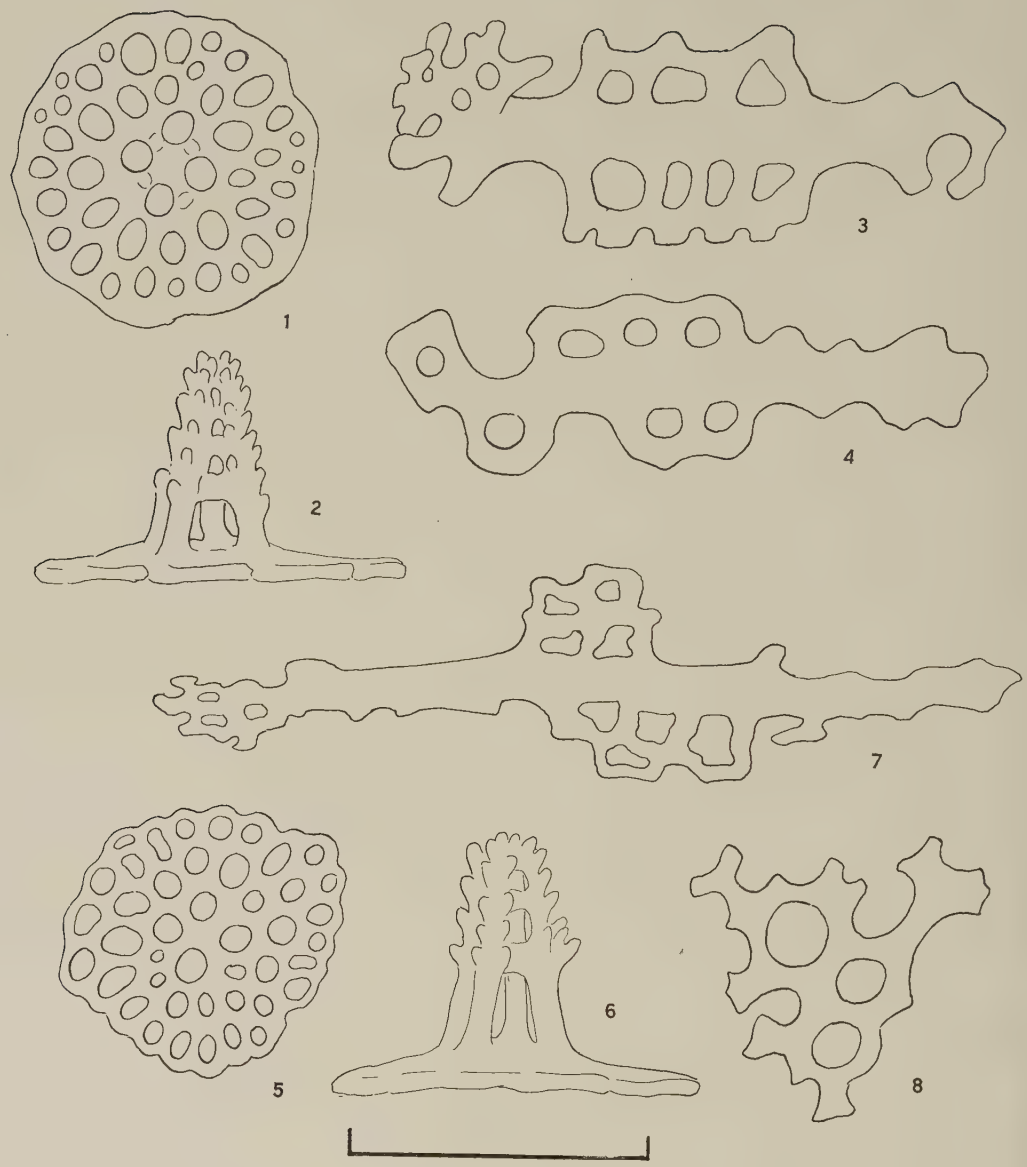
Other localities from which holothurians in the M. C. Z. are specially discussed

1939, May 30. Off Gloucester, about 70 fathoms. J. Miller coll.
Molpadia oolitica (Pourtalès).

18.., S. of Marthas Vineyard Station "Blake".
Chiridota ferruginea (Verrill).



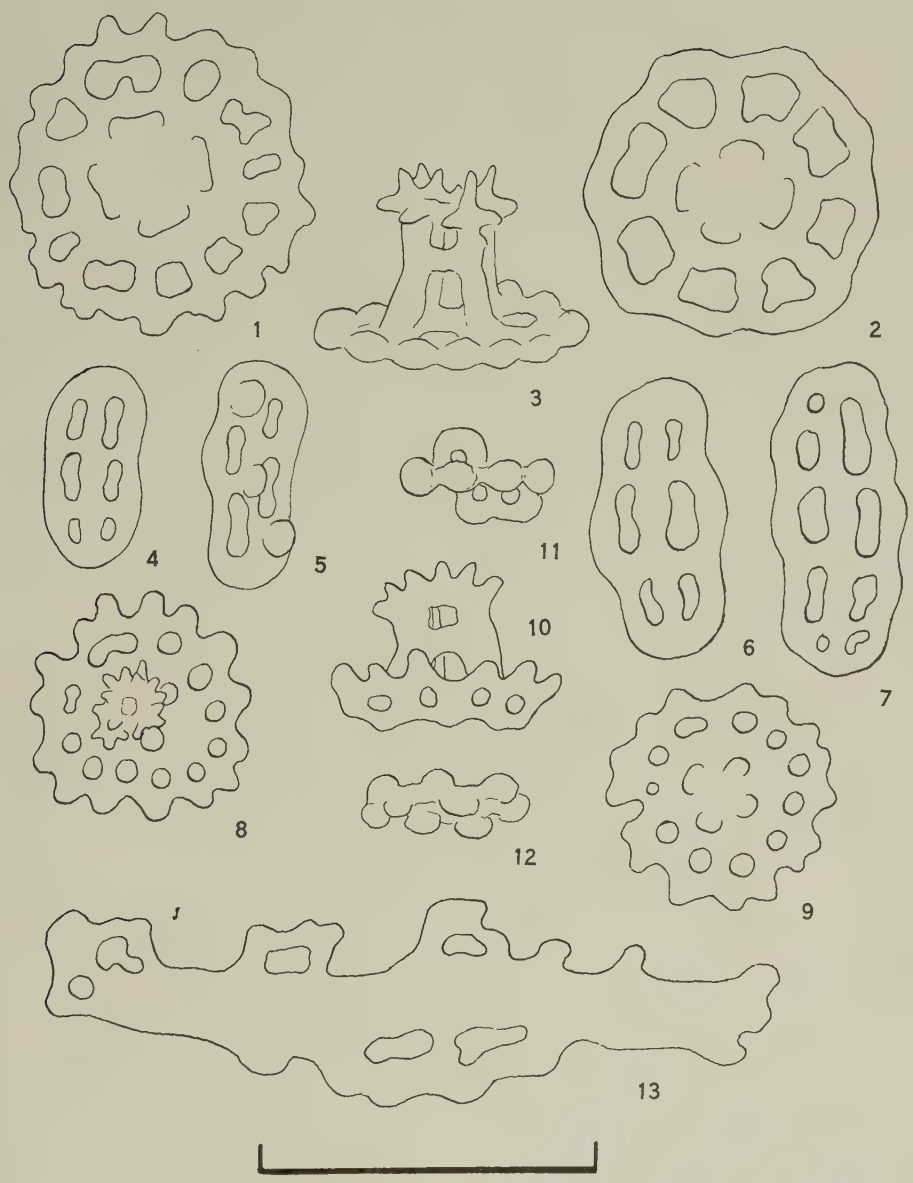
Bathyplotes bigelowi spec. nov.
1 - 2. Table, disk and lateral view of spire.
Bathyplotes pourtalesii (Théel)
3 - 4. Table with cross-shaped disk, disk and lateral view.
Synallactes crucifera Perrier
5 - 6. Cross-shaped deposit and central projection.



Stichopus regalis (Cuvier)

1 - 4. Spicules from a specimen from the Mediterranean Sea; 1 - 2, tables;; 3 - 4, supporting rods from tube feet.

5 - 8. Spicules from a specimen from the West Indian Seas; 5 - 6, tables; 7, supporting rod; 8, reticulated plate from dorsal papilla.

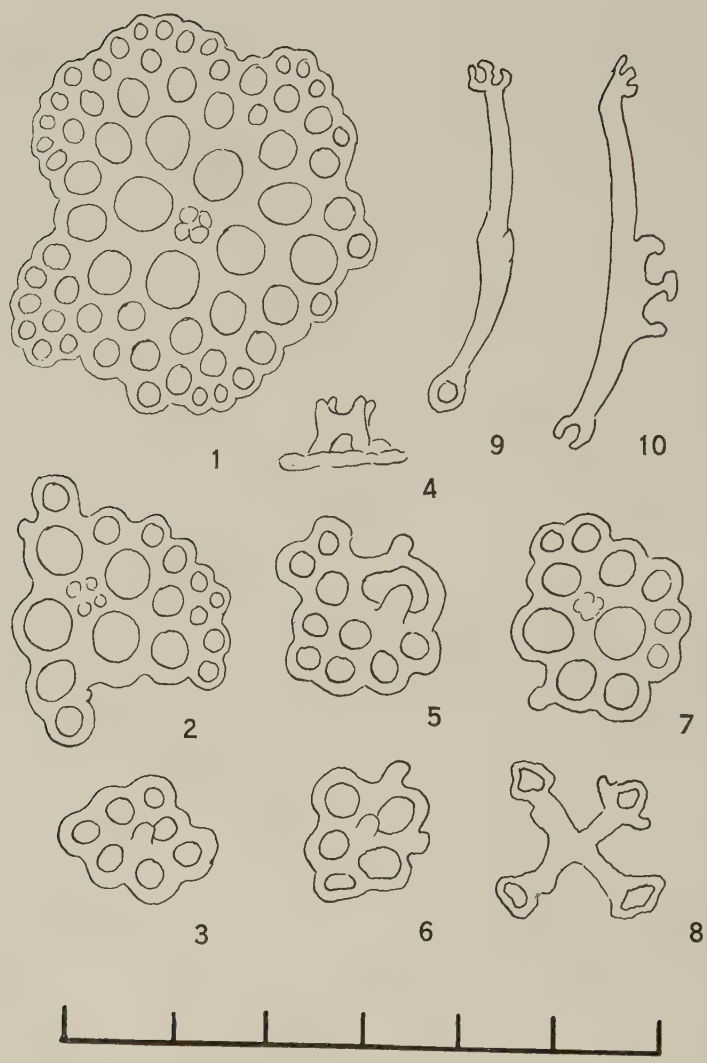


Holothuria lentiginosa v. Marenzeller

1 - 7. Spicules from a specimen collected in the West Indian Seas.
1 - 3. Tables; 4 - 7, buttons.

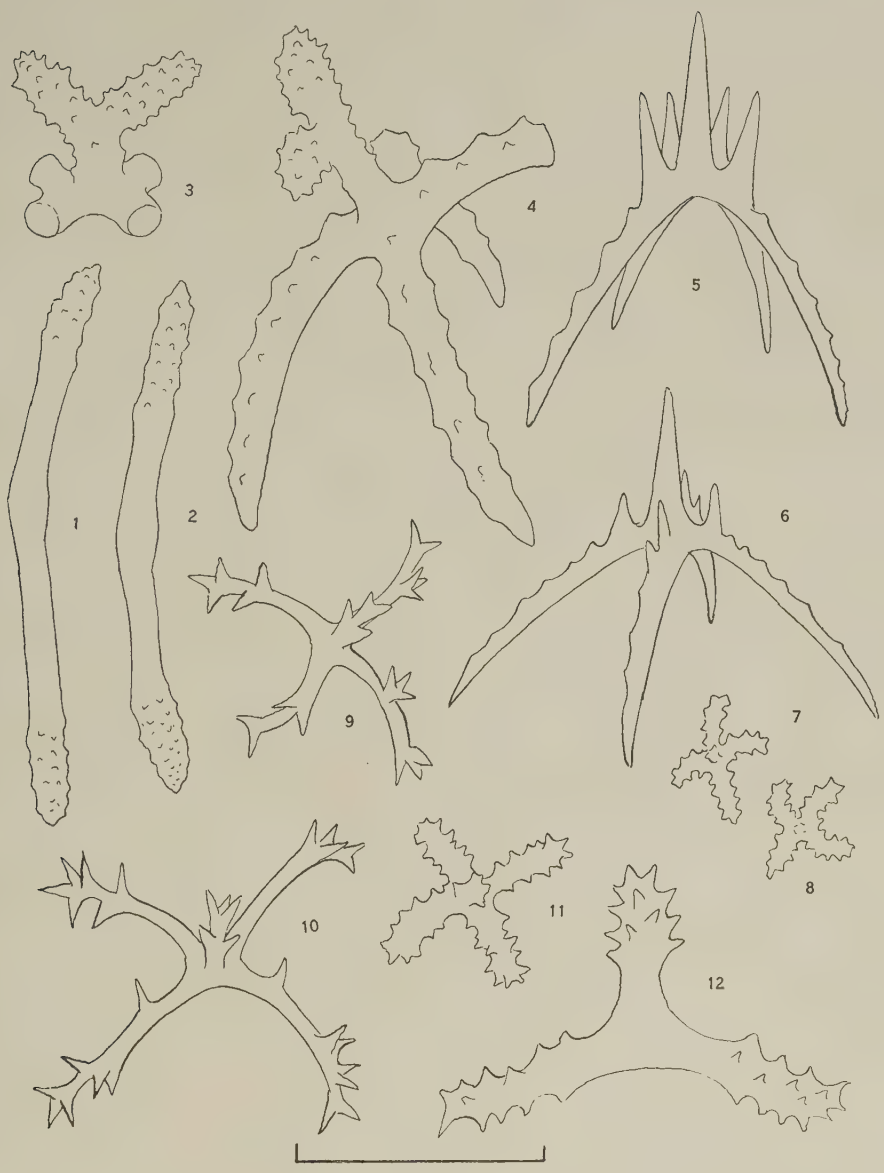
Holothuria occidentalis Ludwig

8 - 10. Tables; 11 - 12, knobbed buttons; 13, supporting rod from tube foot.



Amphigymnas bahamensis Deichmann

1. Large table from integument; 2 - 8, smaller tables or plates from appendages; 9 - 10, supporting rods from tube feet.



Bentrodytes typica Théel

1 - 2. Spinous rods from the integument.

Benthodytes lingua Perrier

3 - 4. Large crosses with bifurcate outer projections (arms partly cut off).

Euphornides violacea Perrier

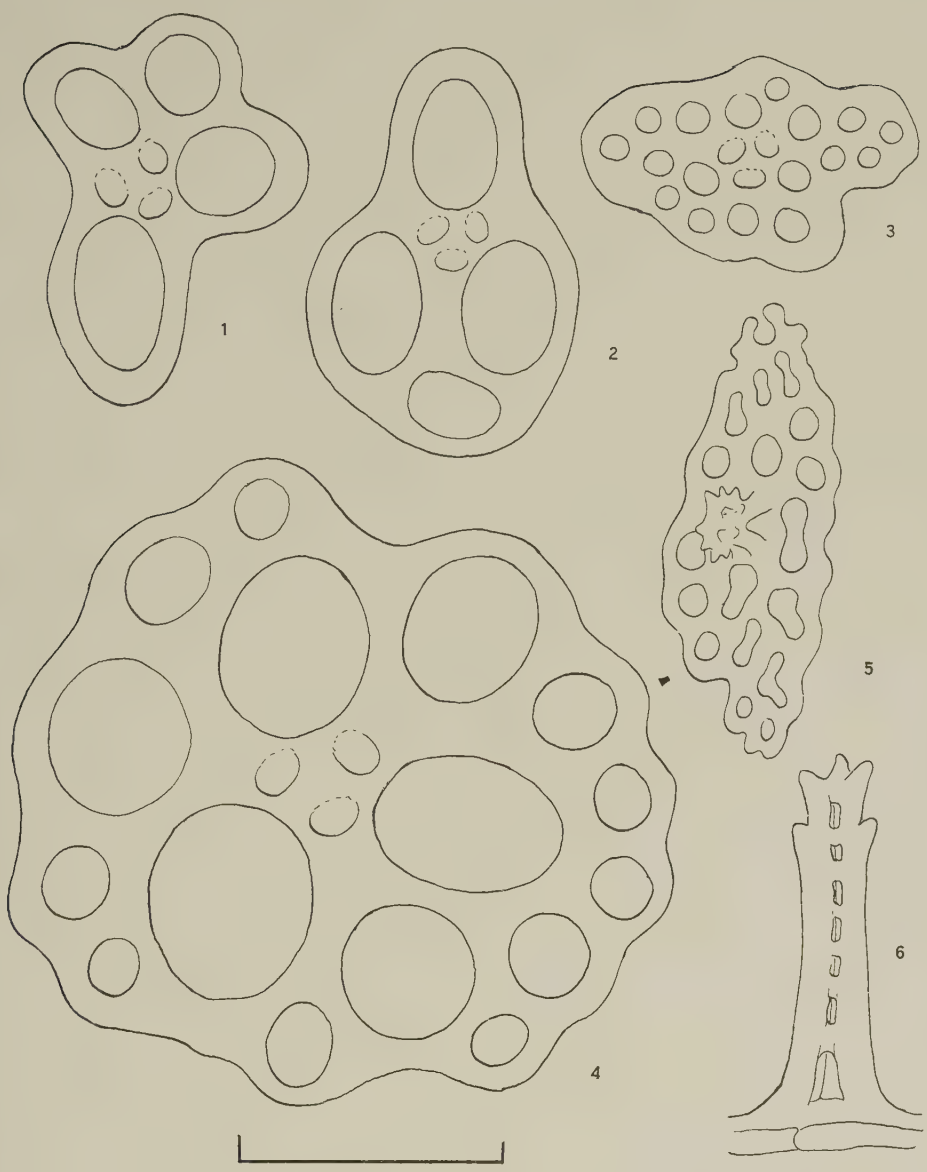
5 - 6. Large crosses from the dorsal side; 7 - 8 small spinous crosses from the ventral side.

Euphornides kerhervei (Hérouard)

9 - 10. Large spinous crosses from the dorsal side. 11 - 12, smaller four and three armed deposits from the ventral side.

Molpadia oolitica (Pourtalès)

1 - 3. Large tables from integument; 4, elongate table from tail end. All from small individuals few cm. long from off Gloucester.

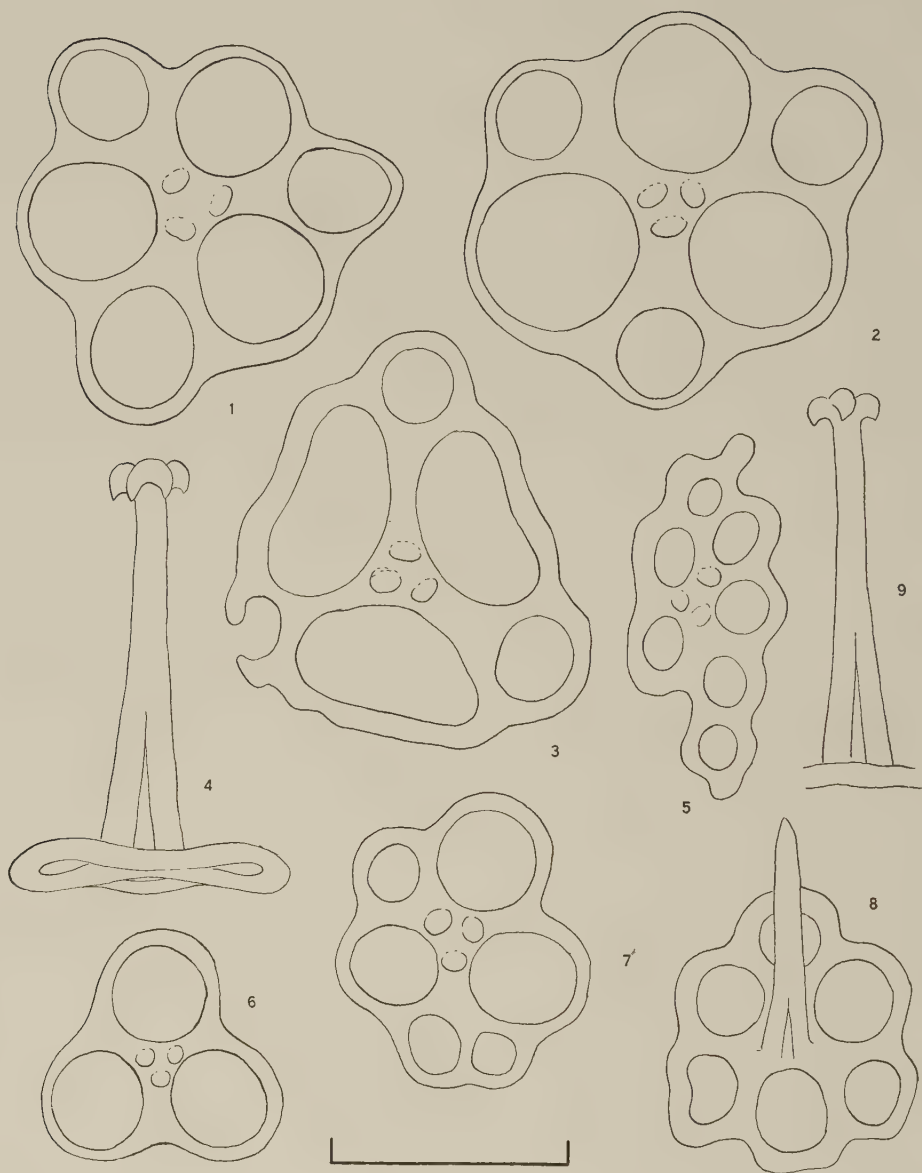


Molpadia cubana spec. nov.

1 - 2. Disk of tables from the integument; 3, disk of table from the tail end.

Molpadia parva (Théel)

4. Disk of table from Théel's type of var. *coerula*; 5, spire from same; 6, table from tail end from same.

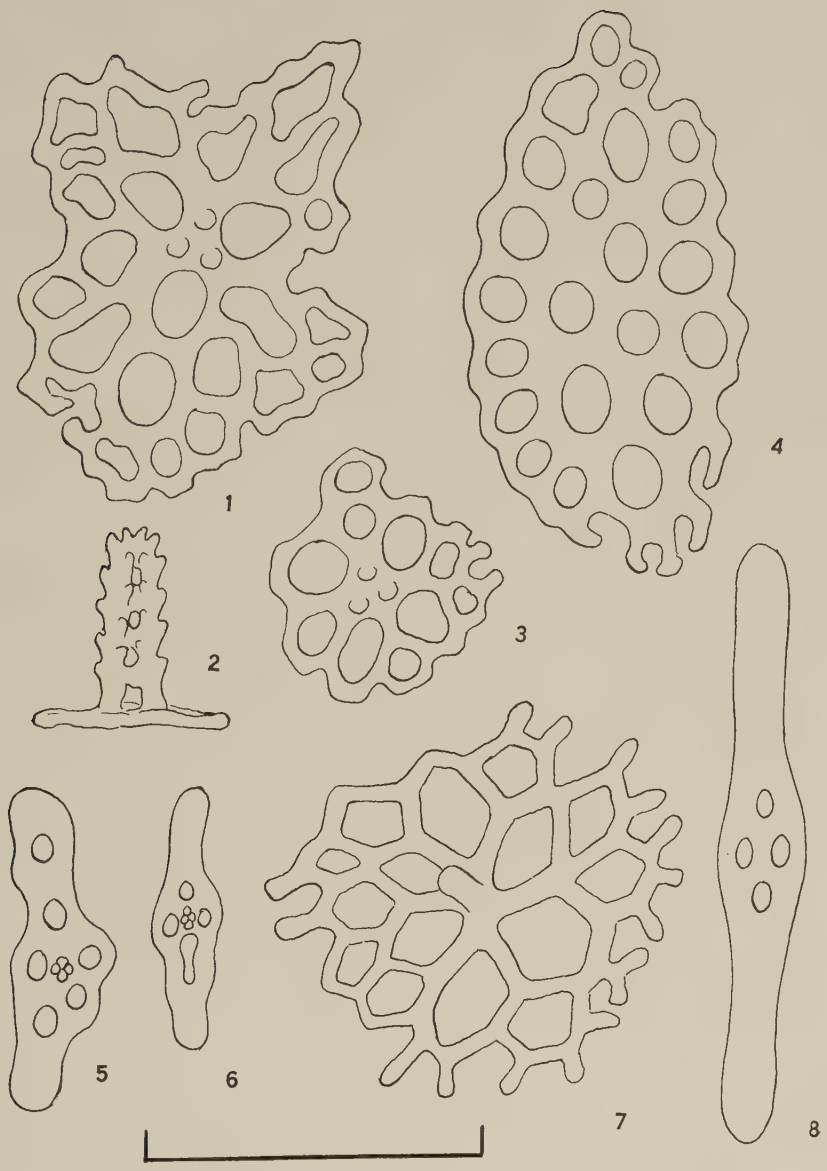


Molpadia parva (Théel)

1 - 3. Disk of tables from Théel's variety *parva*; 4, spire with hooks; 5, table from tail end.

Molpadia blakei (Théel)

6 - 8. Tables from Théel's type specimen; 9, spire with hooks from same.



Molpadia barbouri spec. nov.

1 - 3. Tables, 4 plates with no trace of spire; 5 - 6, fusiform rods from tail end (from type).

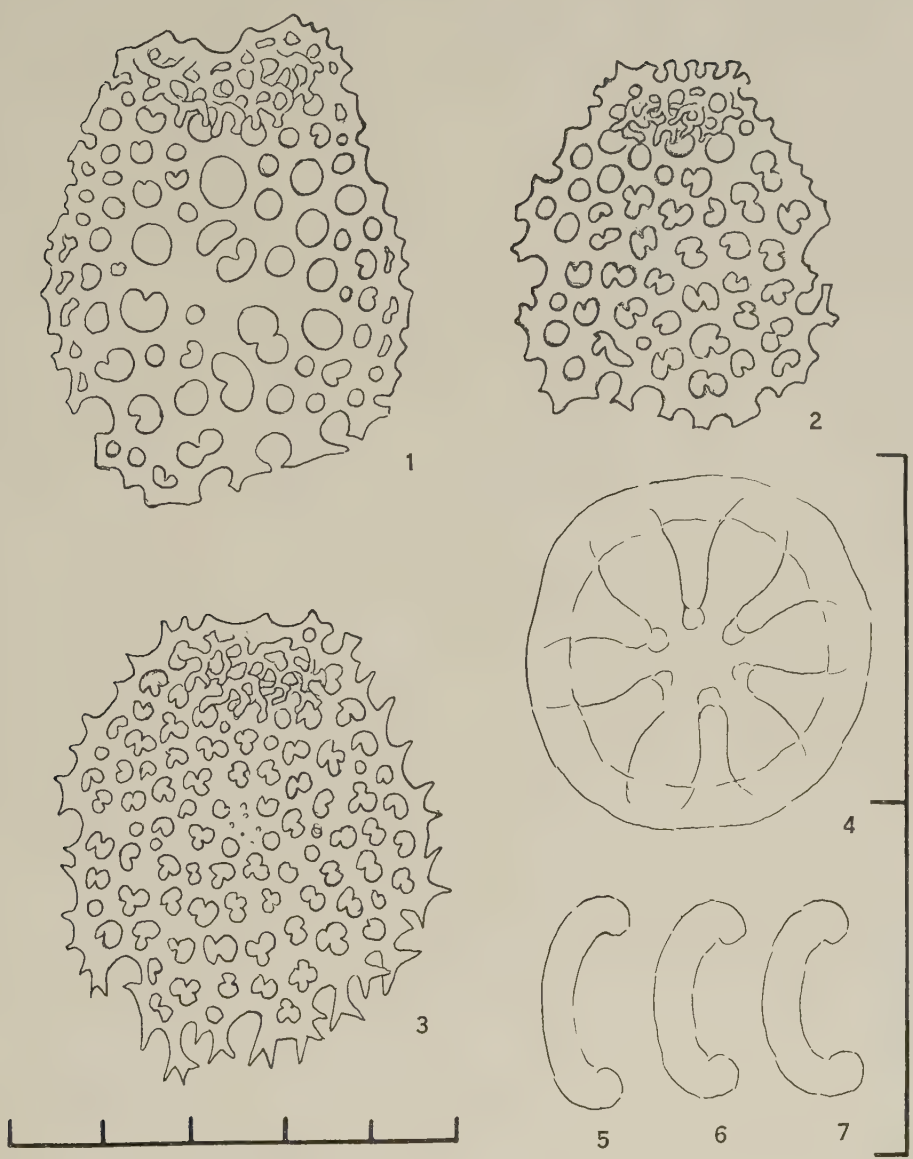
Molpadia agassizi (Théel)

7. Small table; 8, fusiform rod from tail end (from type).

Molpadia musculus (Risso)

1 - 4. Tables and fusiform tables from specimen 1 cm. long; 5 - 9, tables and fusiform plates from specimen 2 cm. long; 10 - 13, tables and fusiform rods from specimen 6 cm. long (*violacea*-type). All from the West Indian Seas.

14 - 15. Table and fusiform plate from specimen from off the coast of New England (*loricata*-type, same as the two smaller specimens from the West Indies).



Protankyra brychia (Verrill)

1 - 2. Anchor-plates from specimens from off New Jersey (Théel's *P. sp.*) and off Cedar Key Florida.

Protankyra pacifica Ludwig

3. Anchor-plate from specimen from off Lower California.

Chiridota ferruginea (Verrill)

4 - 7. Wheel and curved rods from a fragment from off Marthas Vineyard.

Contribution No. 249

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ANNUAL FLUCTUATIONS IN THE ABUNDANCE OF MARINE ZOÖPLANKTON [1]

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From the time of the earliest oceanographic expeditions, it has been recognized that the open oceans are more densely populated in high northern and southern latitudes than in the tropical belts, and that the richest areas of all are boreal coastal waters. But even in these fertile zones, the abundance and character of the plankton is known to fluctuate from time to time. Perhaps the most obvious change is a seasonal one. During the spring a wave of reproduction commonly follows the winter period of scarcity, and later in the summer there may or may not be a second period of increase. However, the seasonal cycle is not constant from year to year either in the numbers or in the species of animals produced. In certain cases, annual changes of this sort have been thought due to fluctuations in the amount of " foreign " water entering a given area from neighboring regions. As a consequence, plankton studies in recent years have frequently centered on a search for " indicator " species which would reveal the presence of intruded water and give a clue to its origin. Possibilities were foreseen of the practical use of such " indicators " in forecasting the success of the fisheries or even in solving complex hydrographic problems (for a recent bibliography, see Russell, 1939; additional references, Pierce and Orton, 1939; Redfield, 1939; Sømme, 1934; Bigelow and Sears, 1937; Report Newfoundland Fisheries Research Commission, 1932; Frost, Lindsay, and Thompson, 1933; Thompson and Frost, 1935, 1936).

By far the most extensive plankton investigations based on the study of " indicators " of this sort has been undertaken at Plymouth, England (Russell, 1939). Of the results obtained perhaps the most suggestive are derived from the fluctuations in abundance of the two chaetognaths, *Sagitta setosa* and *Sagitta elegans,* since the former has almost entirely replaced the latter in the years following 1931. At the same time, in the Plymouth region, there has been a continued impoverishment of the phosphates in the water, a scarcity of fish larvae, and finally a failure of the herring fishery. Since it has been concluded that " *S. setosa* pre-

[1] Contribution No. 249 of the Woods Hole Oceanographic Institution.

dominates off Plymouth when the easterly element in the Dover Straits current is suppressed and the flow of Atlantic water into the North Sea from the north is strong (Carruthers theory) " (Russell, 1935, p. 328), the unusual conditions in the plankton are believed due primarily to changes in water circulation.

There are, however, examples of fluctuations among the planktonic animals of the Plymouth region which are not so clearly correlated with a mixing of water masses. Thus, the two species of the siphonophore genus *Muggiaea*—inhabitants of warm coastal waters generally—do not appear together in the waters off Plymouth: *M. atlantica* has been taken regularly at the Seven Stones lightship between 1913 and 1925, whereas *M. kochii* replaced it after 1925—at least until 1934 (Russell, 1934). It is suspected that both these species are " indicators " of coastal waters from the south, i.e., the shallower waters bordering on the Bay of Biscay. If this is true, there must be some factor (or factors) other than transport by currents responsible for fluctuations of species such as these which are presumably inhabitants of the same water mass. Such differences would be extremely difficult to distinguish in an area such as Plymouth, which is beset by strong tidal currents as well as by ocean currents.

It is the purpose of this paper to call attention to the occurrence of marked fluctuations in the zoöplankton on the continental shelf south of Cape Cod, a region which is not subject to such irregular mass incursions of " foreign " water as invade the Plymouth area. Such fluctuations as those just cited for the two species of *Muggiaea* may be due in part, at least, to limiting factors as subtle as those controlling the size of the different year classes among fish.

In the coastal waters from Cape Cod to Chesapeake Bay, plankton samples were collected by the U. S. Bureau of Fisheries on 23 cruises during the first half of the years 1929–1932 (Bigelow and Sears, 1939). These observations have been supplemented by stations on a section crossing the shelf off Montauk Point on ten occasions between October, 1937 and June, 1939 (Clarke, 1940) and by collections made at the whistle buoy 3 miles off Martha's Vineyard in 1935–1936 (Sta. 3, Clarke and Zinn, 1937) and on other occasions during the summers of 1937, 1938, and 1939 (unpublished data). These data clearly show important fluctuations not only in the total mass of zoöplankton, but also in the abundance of some of the more common species. Here, the waters undergo essentially the same seasonal changes in temperature and salinity each year (Bigelow, 1933; Bigelow and Sears, 1935; Clarke, 1940) following the cycle which is characteristic of boreal waters generally. A considerable amount of highly saline water from beyond the

edge of the continental shelf must enter this region each year to compensate for the large inflow of river water and rain (Iselin, 1939). However, any transport of plankton into this coastal area by this "slope" water (Iselin, 1936, p. 11, Fig. 2) is slight, since there is always a sharp boundary between the populations of the coastal waters and those offshore. In fact, on the routine cruises now being run SSE from Montauk Point to a point the other side of the Gulf Stream, it is usually possible to sort the catches by casual inspection, according to the locality of capture. The catches on the continental shelf consist essentially of the common coastal species (see Bigelow and Sears, 1939); while those in the "slope" water are composed of *Metridia lucens,* rather than *Calanus* or *Centropages,* as the outstanding copepod, *Sagitta enflata,* as the characteristic chaetognath, and usually salps (*Salpa fusiformis, Iasis zonaria*) in some quantity as well as other typically oceanic species (unpublished data; Clarke, 1940). While *Metridia,* it is true, occurs in some numbers over the outer half of the shelf, particularly in the north, we seldom find other oceanic species more than 10–15 miles inside the 200-meter contour.[2] Hence, while there is some possibility of "contamination" by offshore animals in the region under consideration, it seldom affects any considerable area and never for any length of time.

In addition to the increments derived from the "slope" water, our coastal area also receives water in small quantities from the vicinity of Nantucket Shoals, particularly during the spring. We have little reason to suppose, however, that this has any marked effect on the zoöplankton, for during the spring of 1932, when several intrusions of colder water from the north were observed (Bigelow, 1933), the only noticeable effect of this water movement was the introduction of a meager number of *Calanus hyperboreus* and *Oikopleura labradoriensis* into the area south of Cape Cod (Bigelow and Sears, 1939, p. 247). Actually, during the spring, when flooding from the north most often occurs, the chief effect would be a dilution, since at this season the population in the waters of the Gulf of Maine is at its minimum (Bigelow, 1926). Were there to be an intrusion from this source later in the summer, it is unlikely that the nature of the plankton would be appreciably affected, since catches made in September (1939) on the western part of George's Bank and over the continental shelf between Montauk Point and Martha's Vineyard (unpublished data) were of much the same richness and type, chiefly *Centropages typicus.*

[2] The waters may become "overridden" temporarily with warm-water species which reproduce rapidly (i.e., *Salpa fusiformis*—July 6 to mid-August, 1929). But the enormous quantities of these (3,000–5,000 cc. per 20-minute tow with a meter net) are due to local propagation and are not an indication of an unusually large mixing of "slope" water, because other oceanic species occur only as traces.

Nevertheless in this region between Cape Cod and Chesapeake Bay—an area biologically isolated from the "slope" water offshore and only slightly contaminated by the plankton of Nantucket Shoals—*Calanus finmarchicus* showed a 10-fold fluctuation in abundance (by volume) at the season of its greatest richness during the years 1929–1932 (Fig. 1). In addition, when the richest of these periods (July, 1931) is com-

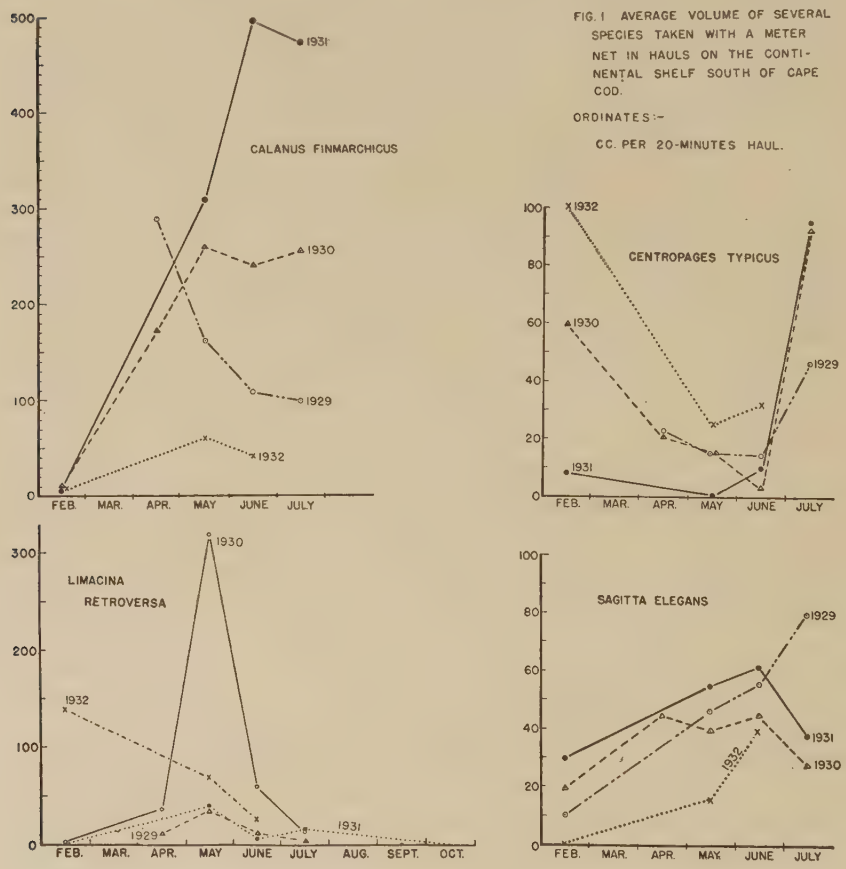

FIG. 1 AVERAGE VOLUME OF SEVERAL SPECIES TAKEN WITH A METER NET IN HAULS ON THE CONTINENTAL SHELF SOUTH OF CAPE COD.

ORDINATES:— CC. PER 20-MINUTES HAUL.

pared with the very poor periods of a few years later (July 1937–1939), a 600-fold difference (by volume) is revealed. Equally great fluctuations in the stock of *Calanus* have been encountered south of Woods Hole in other years when no extensive surveys were undertaken. This copepod was virtually unobtainable in the vicinity of Woods Hole during the past three summers, although it was abundant during 1935 and 1936 (Clarke and Zinn, 1937).

TABLE I

Species	Year of greatest abundance by volume	Year of least abundance by volume
Calanus finmarchicus	1931	1932
Limacina retroversa	1930	1931
Sagitta elegans	1929, 1931	1932
Centropages typicus	1932	1931
Aglantha digitale	1932	1931
Euthemisto compressa	1930	?

Other individual species studied quantitatively during 1929–1932 have similarly undergone marked fluctuations (more especially over the northern half of the area), notably *Limacina retroversa* (12-fold, Fig.

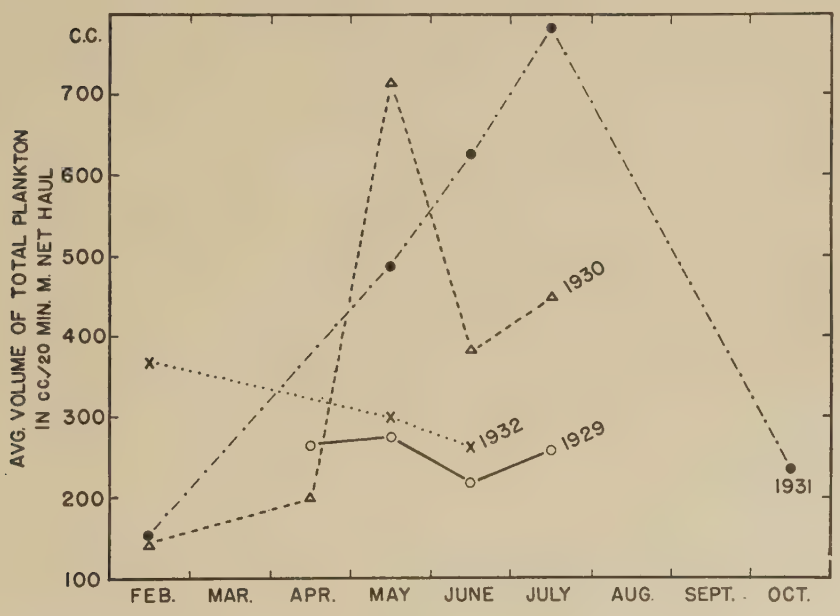

FIG. 2. Average volumes of total plankton.

1), and to a lesser degree *Sagitta elegans* and *Centropages typicus* (Fig. 1). Other members of the plankton which ordinarily occur as odd specimens may become sufficiently numerous in certain years to form a measurable proportion of the total. Such was the case for *Euthemisto compressa* in 1930 and *Aglantha digitale* in 1932. Furthermore, it ap-

pears that these fluctuations occur independently of one another—a year (1931) rich in *Calanus* being poor in *Limacina* or a year (1932) rich in *Centropages* being poor in *Calanus,* etc. (See Table I.)

Not only do individual species exhibit these marked fluctuations, but in addition the plankton as a whole varies in abundance from year to

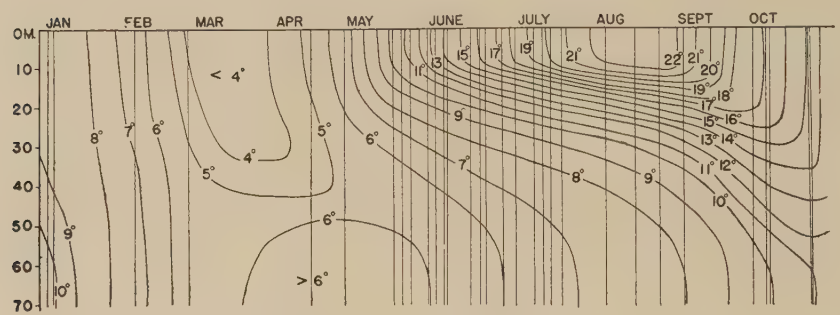

FIG. 3. Average temperatures throughout the year on the continental shelf off Montauk Point, based on all available data.

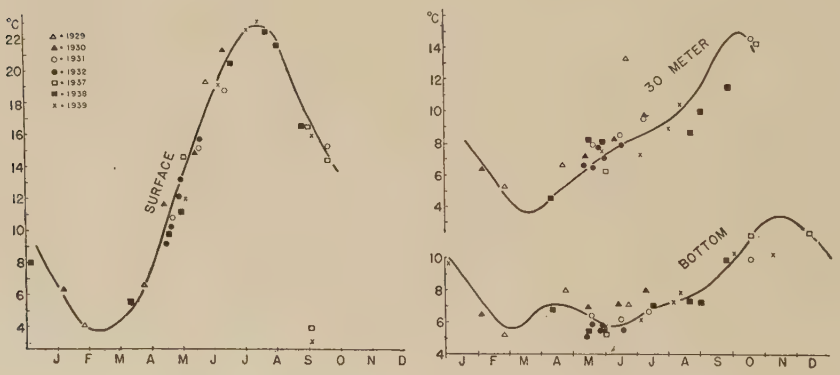

FIG. 4. Departures of temperature from the average seasonal cycle at the surface, 30 meters, and the bottom, for 1929–1932 and 1937–1939, at stations halfway across the continental shelf off Montauk Point.

year (Fig. 2). In the relatively short series of observations (1929–1932), plankton was much more plentiful during the warm winter of 1932 than in the other winters, especially in the south (Bigelow and Sears, 1939), and this condition seemingly continued through late April (judging from a few vertical hauls of about 400 cc. per 20-minute tow—unpublished data). By May and June of that same year, however, the

plankton was distinctly sparse—in fact, as sparse as in 1929. On the other hand, although the plankton had been very poor in the winter of 1931, it was decidedly richer than average during every other month of that year when surveys were made. Earlier surveys had likewise shown similar fluctuations, the plankton being unusually abundant during the cold summer of 1916 and scarce during the warm summer of 1913 (Bigelow, 1926).

Without a longer series of observations we can offer little explanation for these fluctuations. It has been suggested that temperature is the factor in our area which prevents *Calanus* from entering the upper water layers (15–22° C.) in the summer months and restricts this species to the deeper water (7–12° C., Fig. 3). Nevertheless, it does not appear likely that temperature *per se* causes these annual changes in abundance of *Calanus* since the temperature differences are only 1–2° C. between "warm" and "cold" years (Fig. 4)—a difference which would hardly limit the distribution of an animal living over such a wide temperature range as *Calanus*.

We have also made a cursory examination of the salinities and found them to be somewhat more variable locally than the temperatures, from year to year, and even from month to month, especially in the surface layers. However, there appears to be no abnormal mixture of offshore water, the variability seemingly being caused by irregularities in the local rainfall and the inflow from the rivers.

Since the occurrence of wide fluctuations in the abundance of zooplankton in our coastal area now seems well established, further investigation of the consequences of such variation is called for. It is to be hoped, for instance, that a correlation may be found between the richness of the plankton and the fluctuations in the abundance of a commercially important fish such as the mackerel (Sette, 1940), which feeds upon the plankton.

Summary

The abundance of the zoöplankton in the waters overlying the continental shelf between Cape Cod and Chesapeake Bay is shown to be subject to severe annual fluctuations in respect both to individual species and to the total population. Yearly variations of this sort in British waters have been attributed to mass incursions of water from outside sources; but since no great annual differences in the exchange of water masses have been found in the coastal regions treated in this study, our data strongly indicate that important fluctuations in the plankton may occur in relatively undisturbed areas. These changes in the plankton

are not found to be correlated directly with gross environmental changes and therefore must be due to an indirect action of physical or biological factors.

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Contribution No. 250

NOTES AND DESCRIPTIONS OF NEW DEEP-WATER MOLLUSCA OBTAINED BY THE HARVARD-HABANA EXPEDITION OFF THE COAST OF CUBA. III.[1]

BY W. J. CLENCH AND C. G. AGUAYO

This present study continues the reports upon the mollusks collected by the *Atlantis* party off the coast of Cuba. In addition other western Atlantic material, collected by the *Blake* and *Hassler*, that has not been previously reported upon, is included.

Our studies have been materially augmented by the successful dredgings of the *Atlantis* during March to May of 1939. This second Cuban cruise, though in the same waters, yielded many more forms not previously encountered as well as adding substantially to the series of species obtained during its first trip around Cuba the previous year.

A rather remarkable feature indicated by the material collected during both 1938 and 1939 is the large number of new forms that appear to be limited generally to the Old Bahama Channel and westward through the Nicholas Channel, narrow straits of water that separate Cuba from the Bahama Banks. This region is roughly limited by the eastern end of Cayo Romano west along the northern coast of Cuba as far as Matanzas. This area is the extreme western end or the "valley head" of the Brownson Trough, which from here extends eastwardly past the northern coast of Hispaniola as far as Puerto Rico where depths exceeding 4500 fathoms have been recorded.

The small area from which most of these new forms have been collected is in relatively shallow depths, mainly raging between the 150 and 300 fathom contours. West of this area waters deepen to over 1000 fathoms in the Straits of Florida. Factors in the submarine topography of this region may have produced a condition of isolation,

(1) Contribution no. 250, Woods Hole Oceanographic Institution.

creating a comparatively shallow plateau, margined on the north and south by the Bahama Banks and Cuba, and limited on the east and west by the Brownson Deep and the Straits of Florida. New forms are, however, not limited to the mollusks, but many new crustaceans and fishes that seem to be peculiar to this area have also been found.

It is highly probable that ecological conditions in this localized area may be ideal and somewhat uniform and extensive for the new forms encountered. Intensive collecting elsewhere in the West Indian Region may well show a much wider range when bottom conditions are found that at all approximate those obtained here. It is to be reiterated, however, that our general knowledge of the deep water fauna of the entire West Indian region is altogether too fragmentary to base conclusions upon the geographic limitations of any species. Nevertheless, the collecting of the same species in the same area during both dredging trips, species not obtained elsewhere around Cuba, would set off this area as somewhat different.

A somewhat similar condition prevails in the Bahía de Cochinos in southern Santa Clara Province. This is a rather broad, deep bay reaching inland for 16 miles. Several unique species have been discovered in this area, which may indicate that another set of conditions have brought about isolation of some sort, possibly physical, which limit the distribution of these forms. The deep water which occurs off the mouth of this bay may have acted as a barrier to the species that exist only in the more moderate depths.

Calliostoma (Calliostoma) cubanum new species

(Plate 16, fig. 4)

Description. — Shell small to medium in size, somewhat depressed and minutely perforate. Whorls flattened and greatly angled by two strongly developed beaded keels, at the periphery. Color probably a straw yellow (dead and broken when collected). Aperture quadrangular with a simple and a faintly glazed parietal wall. Spire somewhat depressed. Columella nearly straight, rather thin and partially folded over the minute imperforation. Suture not indented. Sculpture consisting of two strongly beaded cords at the whorl periphery, the upper one much the stronger and more heavily beaded. Two strongly beaded and two alternate finely beaded cords between the periphery and the suture. The superior margin of the aperture is built forward and rather fine non-beaded cords. No operculum observed.

Height	*Width*	*Aperture*	
(broken)	16.5	7.6 × 7.5	Holotype

Holotype. — Mus. Comp. Zoöl. No. 135163, *Atlantis* station No. 3474 (N. Lat. 23° 18′; W. Long. 80° 46′) off Cardenas, Matanzas Province, Cuba, May 10, 1939, in 490 fathoms.

Remarks. — The description above is based upon a single dead and broken specimen. This species does not appear to be very closely allied to any other western Atlantic form. The remarkable feature is that of the greatly developed beaded sculpture which exceeds anything known to us in this genus for the size of the shell.

This species is minutely imperforate and should perhaps be considered in the subgenus *Astele* because of this condition. However, the perforation is nearly closed and probably is normally so in live material. In general, its relationships are certainly with *Calliostoma* s. s.

Calliostoma (Calliostoma) torrei new species

(Plate 14, fig. 5)

Description. — Shell large, solid, imperforate and (dull?). Whorls 9½, regularly increasing in size, the last somewhat inflated. Color very probably red or a brownish red. (Single specimen dead when found). Aperture subquadrangular, with a simple lip, produced along the lower margin of the flattened periphery. Parietal wall thinly glazed. Periphery of body whorl obtusely angled. Spire extended and slightly concave, produced at an angle of 76°. Columella thick, inwardly arched and obtusely angled with the base of the aperture. Sutures indented. Sculpture (body whorl) of 19 beaded cords from the lower margin of the flattened periphery above to the suture. These beaded cords are finer on the flattened periphery. Below, the cords are non-beaded. Nuclear whorls are faintly costate.

Height	*Width*	*Aperture*	
40	35.2	26.5 × 28 mm.	Holotype

Holotype. — Mus. Com. Zoöl. No. 135165, *Atlantis* station No. 3985 (N. Lat. 23° 13′; W. Long 81° 22′) off Matanzas, Matanzas Province, Cuba, April 11, 1939, in 385 fathoms.

Remarks. — A single dead specimen only was obtained. This is the largest species of *Calliostoma* known to exist in the Western Atlantic and is exceeded in size by but few species elsewhere. In

of lip sinuous. Parietal wall very thinly glazed. Umbilicus wide and funicular, almost covered by an umbilical pad. Columella thin and nearly straight, forming an obtuse angle with the lip base. In adult shells the umbilical pad is formed by a more or less flat expansion of the columellar fold over the wide umbilicus. Sculpture of numerous fine spiral threads, exceedingly fine on the earlier whorls, increasing in size on the later whorls to become visible to the unaided eye on the body whorl. Axial sculpture of very fine growth lines. Operculum subcircular, multispiral, chitinous and colored a light yellowish-brown.

Length	*Width*	*Height*	*Aperture*	
28.7	19.5	13	10.4 × 9 mm.	Holotype (M. C. Z.)
21.2	18.1	13.1	9 × 8.2 „	Paratype (Poey)
23.5	20	14.2	10.4 × 8.8 „	„ (M. C. Z.)
23	19	13.4	9.5 × 8.1 „	„ „

Holotype. — Mus. Comp. Zoöl. No. 135151, *Atlantis,* station No. 3448 (N. Lat. 23° 21′; W. Long. 79° 56′) off Sagua la Grande, Santa Clara Prov., Cuba, May 3, 1939, in 380 fathoms. Paratypes from the same locality and from the following series of stations all off the northern coast of Cuba. Paratypes deposited in both Mus. Comp. Zoöl. and Mus. Poey. Depths in fathoms.

Station	*N. Lat.*	*W. Long.*	*Locality*	*Depth*	*Date*
3419	22° 46′ 30″;	79° 00′	Off Punta Alegre. . . .	180	April 30, 1939
3448	23° 21′ ;	79° 56′	Off Sagua la Grande.	380	May 3, 1939
3469	23° 12′ ;	81° 22′	Off Matanzas.	425	May 9, 1939
3475	23° 18′ ;	80° 48′	Off Cardenas.	400	May 10, 1939
3476	23° 18′ 30″;	80° 52′	Off Cardenas.	360	May 10, 1939
3485	23° 13′ ;	81° 22′	Off Matanzas.	385	May 11, 1939

Remarks. — This new form differs from the typical species by being much smaller and in having a far more depressed spire. In general appearance it seems nearest to *G. fischeri* Dall but the differences are far less superficial than between *cubana* and *superba.* Though about the same size as *fischeri* our new form differs in having the umbilical pad only partially closing over the umbilicus, a complete closure occurring in *fischeri.* In addition, *fischeri* has a series of strong, comma-like axial ridges on the early whorls which are initiated from the superior suture. These comma-like ridges are even faintly indicated on the nuclear whorls. There are no axial sculptural manifestations, other than the faint growth lines found on both *superba* and *cubana.*

Ficus Röding 1798 (Pirula Lamarck 1799)

The genus *Ficus* has had heretofore but a single species, *F. papyratius* Say, recorded from the Western Atlantic. This species occurs from North Carolina to Venezuela along the American coasts, and does not occur in the West Indies, other than a single Bahama record, so far as we have been able to trace. In this present report we are describing two new forms from fairly deep water off Cuba and off Brasil.

For a complete systematic review of the genus, reference should be made to E. A. Smith (1894, Jour. of Malacology *3*, pp. 64-69) and C. Bayer (1939, Zoologische Mededeelingen *21*, pp. 369-383).

Ficus papyratius Say

Pyrula papyratia Say 1822 (June) Juor. Acad. Nat. Sci. Philadelphia *2*, p. 238.
Pyrula reticulata Lamarck 1822 (August) Anim. s. Vert. *7*, p. 141, no. 9.
Pyrula fortior Mörch 1877, Malak Blätt. *24*, p. 43.

Although this species ranges between North Carolina and Venezuela, it appears to be really abundant in the United States only along the west coast of Florida. However it may occur abundantly in other portions of its range, particularly in the western Gulf region on the Atlantic coast of Mexico, but as yet this area is exceedingly poor in records for all marine mollusks.

F. papyratius exists a short distance below low water line, though on occasion it may invade the inter-tidal area. Other species in the genus, however, occur at fair depths, though so far no really deep water forms have been found. Smith records *F. ficus* Linn. in 35 fathoms (Sulu Sea); *F. gracilis* (= *dussumieri* Kiener) Sby. in 65 fathoms (Bay of Bengal); and *F. investigatoris* Smith in 98-102 fathoms (off the east coast of India). Our new forms exceed these depths (175 and 450 fathoms).

We agree with Smith (l. c. p. 66) that *F. reticulatus* Lam. is a synonyn of *F. papyratius* and not a variety of this species as considered by Bayer (l. c. p. 375). Also, *F. fortir* Mörch, is based on *papyratius*. His very limited description appears to have been made on previously published figures rather than specimens. He gives no records for the Danish West Indies (Virgin Islands) upon which his catalogue was mainly based.

It is difficult to understand why this species appears to be absent from the West Indies, other than the Bahamas, and yet have a range on the continents as far south as Venezuela, though it is to be admitted that there is much collecting to be done, particularly in the southern Caribbean.

Our Bahama record, a single albino specimen, was found at West End Bush, a small and low sandy island 9 miles southeast of Grand Bahama Island. All other West Indian records that we have seen published refer only to the "West Indies".

The following records are based upon the collections of the Museum of Comparative Zoölogy (M. C. Z.); the Academy of Natural Sciences, Philadelphia (A. N. S. P.); the United States National Museum (U. S. N. M.) and the Charleston Museum (C. M.). We are exceedingly grateful to Dr. H. A. Pilsbry, Dr. Paul Bartsh and Miss Emma Richardson for their kindness in submitting their records.

North Carolina: Beaufort (A.N.S.P.); Cape Lookout (U.S.N.M.).

South Carolina: Bird Key, Ball's Bay; Isle of Palms; Magnolia Beach; Sullivan's Island (all C. M.). One of the two specimens in the Isle of Palms lot is an albino, originally contained in the Revenal collection.

Florida: (East coast) Miami (U. S. N. M.); St. Augustine (M. C. Z.). (Lower Keys) Grassy Key (A. N. S. P.; M. C. Z.); Key West (M. C. Z.; U. S. N. M.). (West coast) Between Pavilion Key, Monroe Co. (C. M. Z.) and the Anclote Keys (U. S. N. M.) there are many records contained in the collections of the A. N. S. P. and the M. C. Z., and the U. S. N. M. This area, roughly 200 miles in length, appears to be ecologically one of the favored grounds for its development, at least on the basis of the species being quite abundant. North of the Anclote Keys the records are much fewer and we give the complete record so far available to us. Cedar Keys (M. C. Z.); Indian Pass; Crooked Island; Sr. Joseph Bay (all Calhoun Co., A. N. S. P.); Santa Rosa Island, Santa Rosa Co. (A. N. S. P.); Pensacola (C. M.). This latter record probably from Santa Rosa Island.

Alabama: Mobile (U. S. N. M.). This record undoubtedly refers to some station along the coastal islands rather than a record for Mobile proper. *Ficus papyratius* is strictly a marine species and would not occur alive in brackish water so far as the records indicate and our own field experience would show.

Texas: (State record only, M. C. Z.).
Mexico: Progreso; Silan (A. N. S. P.).
Venezuela: Maracaibo (A. N. S. P.).
Bahamas: East End Bush, Grand Bahama Island (M. C. Z.).

Ficus howelli new species

(PLATE 14, FIG. 2)

Description. — Shell imperforate, thin and rather small in size for this genus. Color a yellowish straw, with a series of small, dark reddish-brown dots aranged in six spiral rows. Whorls 4¾, regularly enlarging. Aperture sub-elliptical in shape with a somewhat extended canal below. Spire slightly elevated. Outer or palatal lip thin. Columella extended, slightly twisted, narrowly truncated and somewhat inwardly arched. Sculpture consisting of a reticulated pattern, produced by flattened axial and spiral threads, the alternate spiral threads being slightly stronger, particularly above the mid region of the body whorl. Nuclear whorl glass-like and smooth, the second whorl developing faint axial threads which shortly cross with spiral ridges producing the reticulated pattern, which becomes enlarged and much stronger on the body whorl.

Length	*Width*	*Aperture*	
36.5	19.3	34.2 × 11.4 mm.	Holotype

Holotype. — Mus. Comp. Zoöl. No. 135140, *Atlantis* station No. 3332 (N. Lat. 22° 09′ 30″; W. Long. 81° 11′), Bahia de Cochinos, Santa Clara Province, Cuba, April 5, 1939, in 175-225 fathoms.

Remarks. — This species differs from *Ficus papyratius* Say by possessing much finer sculpture, a more produced spire and in having a larger number of whorls in proportion to its size.

Ficus atlanticus new species

(PLATE 14, FIG. 1)

Description. — Shell small for the genus. Color a dull(?) yellowish-brown, with a series of 11 rows of small reddish brown dots definitely arranged in spiral rows and somewhat off-set axially on the earlier portion of the body whorl. Whorls 4¾ regularly increasing in size. Aperture sub-elliptical with a shortened canal. Spire slightly elevated. Outer lip very thin. Columella slightly extended, faintly twisted, narrowly truncated and straight. Sculpture of a fine reticulated pattern produced by raised axial and spiral threads, the spiral threads being stronger. Nuclear whorl smooth, the second whorl showing the start of the fine reticulated pattern.

Length	*Width*	*Aperture*	*Whorls*	
38	15.8	24.7 × 9 mm.	4¾	Holotype

Holotype. — Mus. Comp. Zoöl. No. 104657, *Hassler* Voyage (S. Lat. 11° 49′; W. Long. 37° 10′) off Sao Salvador, Bahia Prov., Brasil, Jan., 1872, in 450 fathoms.

Remarks. — This species differs from *F. howelli* in being smaller, having coarser spiral sculpture, more numerous spiral dots and possessing a straight columella. Its much smaller size, finer sculpture and elevated spire differentiates it from *F. papyratius.*

Columbarium bartletti new species

(Plate 14, fig. 3)

Description. — Shell thin, probably dull, elongated and spinose. Color a creamy-yellow. Whorls 10, regularly increasing in size. Nuclear whorls (2) bulbous, smooth and glass-like, remaining whorls sculptured. Aperture subquadrate, the basal area near the axis extended to form a very lengthened and narrow canal. Spire extended. Outer or palatal lip of the aperture thin and not expanded. Columella straight and extended below to form the axis of the lengthened canal. Sculpture of rather numerous, long, flattened (horizontally) spines developed on the acutely keeled periphery. The spines are extended horizontally or slightly deflected downwardly. Sculpture on the earlier whorls consists of a few fine but irregular threads above and below the periphery but most prominent near the base of the spines. Below the periphery on the body whorl the spiral sculpture is strong and consists of many regular oblique threads which extend halfway down the canal. Axial sculpture consists of numerous and very fine growth lines extending even out on the spines. Above the periphery there is a series of strong bosses which form a crenulated ridge free from the whorl above. This condition produces a deep and distinctive channel running around the suture. These bosses appear distinctly at the fifth whorl, continuing and becoming increasingly stronger towards the last whorl.

Length	*Width (exclusive of spines)*	*Length of canal*	
39.3	8.2	20.1 mm.	Holotype
35	8	18.7 „	Paratype

Holotype. — Mus. Comp. Zoöl. No. 104729, *Blake* station No. 9 (N. Lat. 18° 12′; W. Long. 78° 20′) off Homers Cove, Westmoreland, Jamaica, 1880, in 254 fathoms, Commander J. R. Bartlett, U. S. N.

collector. A single paratype from the same station and locality deposited in the Museo Poey.

Remarks. — This new form is strikingly similar in general appearance to *C. atlantis* Cl. and Ag. from off the northern coast of Cuba. The sculpture, in *C. bartletti,* however, is very different in the possession of the sutural channel and the series of elevated bosses which form its outer margin. In addition, the spiral sculpture on the basal canal though similar is much more strongly developed.

Our present new form is named for Commander J. R. Bartlett, who was in charge of the *Blake* during its western Caribbean cruise in 1880.

Aurinia H. and A. Adams 1853

Genotype, *Voluta dubia* Broderip

So far as known, this genus occurs only in the western Atlantic from North Carolina south to Barbados and in the Gulf of Mexico. Most of the species are to be found in fair depths other than *A. junonia* Shaw which frequents the shallow water mainly on the Florida shelf along the Gulf side of the peninsula. This species probably never invades the intertidal area alive though dead specimens are frequently found washed up on the west coast beaches. The following is a list of the known species with notes on other distribution and relationships.

Dall has stated (1907, Smithsonian Misc. Collection *48*, p. 366) that *Aurinia* is without a radula, but this was apparently overlooked owing to its very small size. The radula, about one millemeter in length, and less than a tenth of a millemeter in width, consists of a single longitudinal row of rachidian teeth. One is figured under *A. dohrni florida.* Very probably *A. jononia* also possesses a radula. (Text figure 1).

Aurinia dubia Broderip

Voluta dubia Broderep 1828, Zool. Journ. *3*, p. 81, pl. 3, f. 1 (Locality unknown).

The exact status of this species still remains uncertain. The original specimen of Broderip was lost and most subsequent descriptions and figures have been based upon Broderip's drawing. Nothing among any of our recent species in the West Indies agrees

with Broderip's description or figure, though the color pattern is quite typical for all members of this genus.

We are unable to determine just what Dall considered as this species; very probably, however, the forms we consider as *A. dohrni florida* (see below).

Aurinia dohrni Sowerby

(Plate 16, fig. 2)

Voluta dohrni Sby. 1903, Jour. of Malacology *10*, p. 74, pl. 5, fi. 8.

Dohrn redescribed (see next species) what he believed to be *dubia* and figured three specimens. Sowerby questioned Dohrn's determination and renamed the species *dohrni*. However, he did not refer to Dohrn's figures as types but figured another specimen which is not, in our opinion, the same as that figured by Dohrn. The specimen figured by Sowerby was smooth, with full convex whorls while that of Dohrn consists of strongly nodulose and costate examples.

Both forms are in our possession, part of the original lot seen by Dohrn. We certainly agree with Sowerby that the specimens described by Dohrn are not *dubia* Broderip, and as a consequence of Sowerby's error, Dohrn's figures are still unnamed. We propose the following:

Aurinia dohrni florida new name

(Plate 16, fig. 1; text fig. 1)

Voluta dubia Dohrn 1879, Jahr. Deut. Malak Gesel. *6*, pp. 150-156, pl. 4, fig. 13, non *dubia* Broderip 1828.

The type of *A. dubia florida* to be Dohrn's figure 1, on plate 4 on the above citation.

A single dead specimen was collected by the *Atlantis* off Punta Alegre, Camaguey Prov., Cuba. (N. Lat. 22° 48′; W. Long. 78° 50′), March 11, 1938, in 210 fathoms. We also possess a few specimens collected by the *Blake* off the lower Florida Keks.

Aurinia robusta Dall

Aurinia robusta Dall 1889, Bull. Mus. Comp. Zool. *18*, p. 156, pl. 35, fig. 2.

This is a rather stout species with strong nodules on the periphery of the early whorls. The *Atlantis* obtained several examples off the

northern coast of Cuba. Dall's records are taken from his 1907 report as well as that above.

ATLANTIS RECORDS

Station	*N. Lat.*	*W. Long.*	*Locality*	*Depth (fms.)*	*Date*
2980A	22° 48′ ;	78° 41′	Off Punta Alegre. . .	220-250	March 10, 1938
3415	22° 51′ 30″;	78° 55′ 30″	Off Punta Alegre. . .	210	April 4, 1939
3417	22° 50′ ;	78° 56′	Off Punta Alegre. . .	200	April 30, 1939
3423	22° 50′ ;	79° 08′	Off Caibarien.	245	April 30, 1939
3414	22° 50′ 30″;	78° 52′	Off Caibarien.	230	April 29, 1939
3427	22° 52′ 30″;	79° 20′	Off Caibarien.	240	May 1, 1939
2983	23° 11′ ;	79° 08′	Off Santaren Channel	235-260	March 12, 1938
2988	23° 15′ ;	79° 57′	Off Sagua la Grande.	380	March 14, 1938
3445	23° 22′ ;	79° 53′	Off Sagua la Grande.	330	May 3, 1939

ALBATROSS and BLAKE records (Dall)

Station	*N. Lat.*	*W. Long.*	*Locality*	*Depth (fms.)*	*Date*
Blake.					
(55)	23° 9′ 5″;	82° 21′ 5″	Off Havana.	242	1877-78
Albatross.					
	28° 42′ ;	86° 36′	Gulf of Mexico.	280	——
——	——	——	Off Cozumel Island. .	231	——

Aurinia bermudezi new subspecies

(PLATE 16, FIG. 3)

Description. — Shell elliptical in outline and rather solid. Whorls 5, slightly convex and slightly angled at the periphery. Color ivory white with 8 spiral rows of chocolate colored spots, the spots more or less square in outline. Aperture long and elliptical ending below rather acutely with the moderately extended canal. Outer lip thin on its edge but thickened within. Columella nearly straight with five rather strongly developed plicae, the three middle plicae being much the stronger and being slightly broader at the top as well as being flat. Sculpture of very fine axial and spiral threads on the upper whorls, the spiral threads being somewhat the stronger. Periphery of whorl considerably above the middle and produced by a series of close and slightly axially lengthened knobs or nodules which nearly disappear on the body whorl near the aperture. The fine sculpture so prominent on the early whorls is just visible with a 14 power lens on the body whorl above the peripheral knobs. Nuclear whorls rather small for this genus but possessing a well developed calcarella.

Length	*Width*	*Aperture*	
59.2	20.4	42.2 × 9.1 mm.	Holotype

Holotype. — Mus. Comp. Zoöl. No. 135245 *Atlantis* station No. 2962 (N. Lat. 22° 07′; W. Long. 81° 08′): Bahia de Cochinos, Santa Clara, Cuba, Feb. 24, 1938, in 180-190 fathoms.

Remarks. — Apparently related to *A. dohrni* Sby. differing by being somewhat narrower and particularly by possessing large columellar plicae.

Aurinia neptunia new species
(Plate 16, fig. 5)

Description. — Shell strong, rather shiny and fusiform. Whorls 4½ (young) and moderately convex. Color yellowish straw to ivory, with rather broad interrupted spiral bands of chocolate-brown. Spire rather extended. Aperture sub-elliptical, and lengthened. Columella nearly straight with three rather weak plicae, the upper or superior one being the least developed. Sculpture of numerous incised spiral grooves, plainly visible to the unaided eye. Nuclear whorls large and possessing a very prominent calcarella.

Length	*Width*	*Aperture*	
50.5	18.1	35 × 8.5 mm.	Holotype

Holotype. — Mus. Comp. Zoöl. No. 119025, Blake station No. 8, (N. Lat. 17° 45′; W. Long. 77° 58′ 40″), off Banner Reef, Pedro Bank, 75 miles south of Jamaica, 1880, in 322 fathoms.

Remarks. — This species is characterised mainly by its very large nuclear whorls and the broad spiral color bands. It does not appear to be closely allied to any other species in the genus. The single specimen is probably only half grown but larger specimens would differ only in size to judge by many examples in this genus that we have studied.

Aurinia junonia Shaw

Voluta junonia G. Shaw 1808, The Naturalist's Misc. *19*, p. 815.

According to Sherborn, Hwass as an authority for this species cannot be used as his description appeared in volume 11 of the Conchylien-Cabinet (first series) which is now considered non-binomial. (Sherborn, C. D. 1902, Index Animalium, p. 37, bibliography). The first use of the name after Hwass was that of Shaw quoted above and the name will have to date from 1808.

Dall instituted the genus *Maculopeplum* (Nautilus *19*, p. 143, 1906) with this species as its genotype. He attempted, at that time,

to separate this species from the genus *Scaphella* with which it had been included and with which it certainly did not belong. However, he had apparently not come to associate the name *Aurinia* as a genus to include *junonia*. In 1907 (Smithsonian Misc. Collection *48*, p. 370) in his review of the American Volutes he notes the association but still retained the name *Maculopeplum* for *junonia* and added *M. dohrni* to this genus. Other closely related species in this group he considered under *Aurinia*. In our opinion, all of these species are members of a single homogenus group and cannot be separated upon any characters beyond those of specific value. All of the characters that he mentions for *Maculopeplum* apply equally as well to *Aurinia*.

Aurinia junonia is one of the most sought after of Florida shells. Though not at all common in collections, it is far more so now than formerly as the west coast sponge fishermen have become exceedingly aware of the commercial value of this, as well as other rare shells, and are offering many for sale in the shell stores that are scattered along the Gulf coast between Fort Myers and the Cedar Keys. Occasional examples are washed up on the west coast beaches and recently a few specimens have been dredged from 3 to 7 miles off Sanibel Island in 4 to 7 fathoms by Dr. L. M. Perry and Mrs. F. R. Schwengel. Distribution is as follows. United States National Museum records are from Dall's 1907 report.

North Carolina: 17 miles off Cape Lookout, 22 fms. (U. S. N. M.)

Florida: Tarpon Springs; off Tampa Bay; Sanibel Island; off Cape Sable; Florida Keys (all U. S. N. M.) Sanibel Island (M. C. Z.)

Bahamas: Nassau (U. S. N. M.) [may possibly have been originally collected elsewhere].

Barbados: 100 fathoms (U. S. N. M., from *Hassler* voyage). The last record was based on a dead specimen and it is quite possible that it is not *junonia* but one of the several other closely related species. We have not seen the specimen.

Cuba: Matanzas Bay (Jimeno). Not seen by us.

Aurinia gouldiana Dall

Voluta gouldiana Dall 1887, Conch. Exchange [Nautilus] *2*, p. 10.
Voluta (Aurinia) gouldiana Dall 1889, Bull. Mus. Comp. Zoöl. *18*, p. 154, pl. 39, figure 3.

This species extends from Cape Fear, North Carolina (U. S. N. M.) south to Key West. Our present series from the *Atlantis* dredgings extends the range eastward through the Old Bahama Channel.

Station	N. Lat.	W. Long.	Location	Depth (fms.)	Date
3951	26° 08′	79° 02′	Off Gt. Issac, Bimini Bahamas.	155	Feb. 3, 1938
2980A	22° 48′	78° 41′	Off Punta Alegre. . . .	220-260	March 10, 1938
3432	23° 05′	79° 29′	Off Caibarien.	250	May 1, 1939
3437	23° 05′	79° 37′	Off Caibarien.	260	May 2, 1939
3446	23° 21′ 30″	79° 54′	Off Sagua la Grande..	360	May 3, 1939

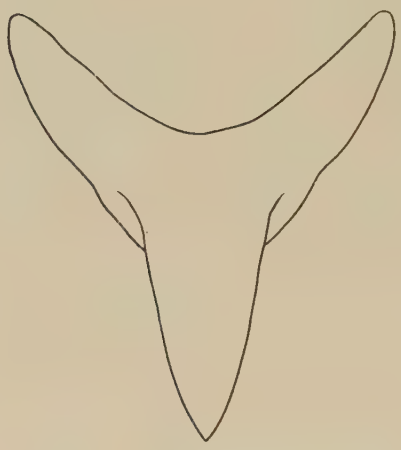

FIG. 1

Rachidian tooth of *Aurinia dohrni florida* Clench & Aguayo.

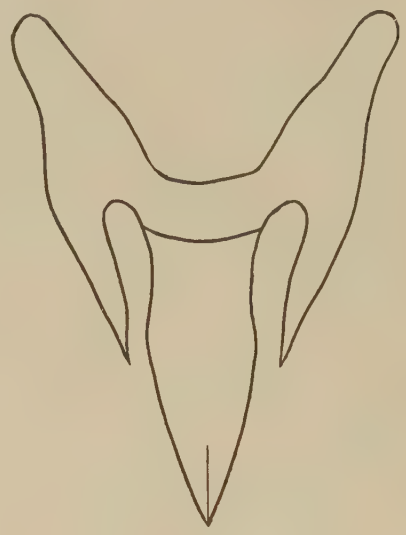

FIG. 2

Rachidian tooth of *Bathyaurinia torrei* (Pilsbry).

AURINIA SCHMITTI Bartsch

Aurinia schmitti Bartsch 1931, Jour. Washington Acad. Sci. *21*, p. 539, fig. 1.

This is a long slender shell with rather faint spiral rows of dots. According to Bartsch it is closely allied to *A. dubia* Brod. differing mainly by possessing a broader posterior angle to the aperture.

Type locality. — South of Tortugas, Florida. 80 fms. (U. S. N. M. no. 382779).

Bathyaurinia new genus

Shell elogate, shining, usually shouldered and with nodules or subcostate whorls. No columella folds or plicae. Radula exceedingly small (2 mm.) consisting of a single row of rachidian teeth.

Genotype, *Aurinia torrei* Pilsbry.

This genus differs from typical *Aurinia* by lacking all of the columellar plicae, by possessing a shining outer surface, usually devoid of spiral sculpture on the later whorls and lacking the regular spiral spotting that is characteristic of *Aurinia*. The mantle very probably envelops the shell. (Text figure 2).

Bathyaurinia torrei Pilsbry

Aurinia torrei Pilsbry 1937, Nautilus *51*, p. 37, pl. 4, fig. 1 (off Cayo Francés, Caibarién, Cuba, in 10 fathoms).

All of the following records are from the *Atlantis*. Depths are in fathoms.

Station	*N. Lat.*	*W. Long.*	*Location*	*Depths*	*Date*
3405	22° 38′	78° 25′	Off Cayo Coco.	235	April 28, 1939
2980	22° 48′	78° 41′	Off Punta Alegre. . . .	220-260	March 10, 1938
2982E	22° 45′	78° 35′	Off Punta Alegre. . . .	150-180	March 11, 1938
3434	23° 10′	79° 35′	Off Sagua la Grande..	260	May 1, 1939
3332	22° 09′ 30″	81° 10′	Bahia Cochinos.	220	April 4, 1939
3435	23° 05′	79° 25′	Off Caibarien.	255	May 1, 1939
3409	22° 44′	78° 41′	Off Punta Alegre. . . .	200	April 29, 1939
3407	22° 42′	78° 39′	Off Punta Alegre. . . .	200	April 29, 1939
3388	22° 32′ 30″	78° 09′	Off Cayo Romano. . .	255	April 26, 1939
3438	23° 05′ 30″	79° 38′	Off Sagua la Grande..	265	May 2, 1939

Bathyaurinia piratica new species

(Plate 15, fig. 2)

Description. — Shell large, elongate and rather thin. Whorls 6, shouldered and rather strongly convex. Color probably yellowish to yellowish-pink. Aperture elongate. Spire extended. Columella straight and devoid of plicae. Suture faintly indicated, sutural area greatly depressed with the whorls more or less shingled. Sculpture of narrow and moderately developed axial costas on the early whorls. Spiral sculpture of very fine threads, crossed by axial growth lines which are both best developed in the columellar region.

Length	*Width*	*Aperture*	
93.5 +	41.8	55+ × 21 mm.	Holotype

Holotype. — Mus. Comp. Zool. no. 135235, *Atlantis* station no. 2982A (N. Lat. 22° 48′; W. Long. 78° 50′) off Punta Alegre, Camagüey, Cuba, March 11, 1938, in 210 fathoms.

Remarks. — This species appears to differ rather sharply from *B. torrei,* by being much larger, possessing finer sculpture and having a broadly rounded and smooth whorl shoulder. It also lacks the irregular color spots of *torrei.* It agrees with *B. torrei* in lacking all columellar plicae and probably possessing the same general ground color of pinkish-yellow.

We possess only a single broken specimen, but enough remains to show a species quite different from *torrei* which was only recently described from this same general, and almost wholly unexplored, territory off the northern coast of Cuba.

Cochlespira (Ancistrosyrinx) radiata cubana new subspecies

(Plate 15, fig. 1)

Description. — Somewhat smaller than the typical form for the same number of whorls, and having only 16 instead of 25 spines on the peripheral carina. In addition, the spines are larger. Other characters very similar to *radiata.*

Length	*Width*	*Whorls*	
18	7.8 mm.	9	Holotype (M. C. Z.)
14.5	6.5 „	8	Paratype (Mus. Poey)

Holotype. — Mus. Comp. Zoöl. no. 135194, *Atlantis* station no. 3332 (N. Lat. 22° 9′ 30″; W. Long. 81° 11′) Bahia de Cochinos, Santa Clara, Prov., Cuba, April 5, 1939. in 175-225 fathoms. Paratypes from the same locality deposited in the Mus. Comp. Zoöl. and the Mus. Poey. A single paratype from *Atlantis* station no. 3333 (N. Lat. 22° 13′; W. Long. 81° 11′) Bahia Cochinos, April 6, 1939, in 190-200 fathoms.

Remarks. — Harris has pointed (Palaeontographica Americana, *2,* pt. 7, p. 44, 1937) that *Cochlespira* Conrad 1865, replaces *Ancistrosyrinx* Dall 1881 as a genus, but that the latter can be retained as a subgenus for species having funnel-shaped whorls and often possessing serrated carina.

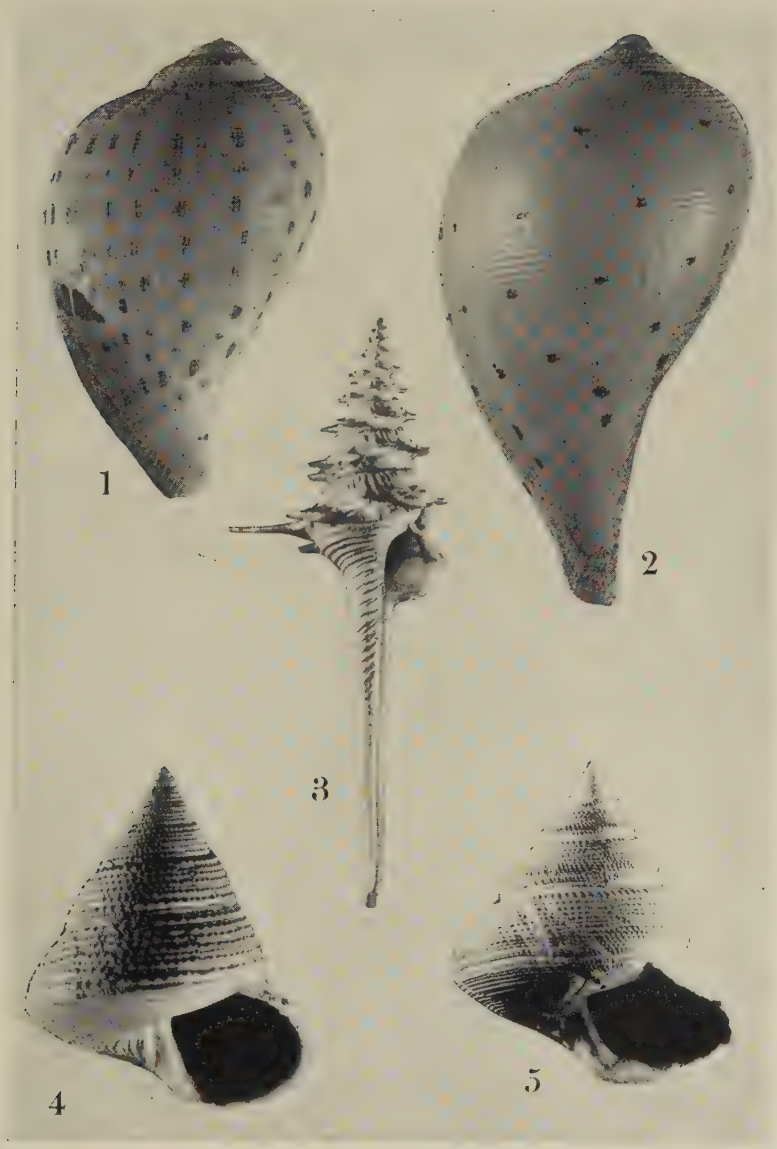

FIG. 1. – *Ficus atlanticus* Cl. and Ag. Holotype. 2 ×.
„ 2. – *Ficus howelli* Cl. and Ag. Holotype. 2 ×.
„ 3. – *Columbarium bartletti* Cl. and Ag. Holotype. 2 ×.
„ 4. – *Calliostoma carcellesi* Cl. and Ag. Holotype. 2 ×.
„ 5. – *Calliostoma torrei* Cl. and Ag. Holotype. Nat. Size.

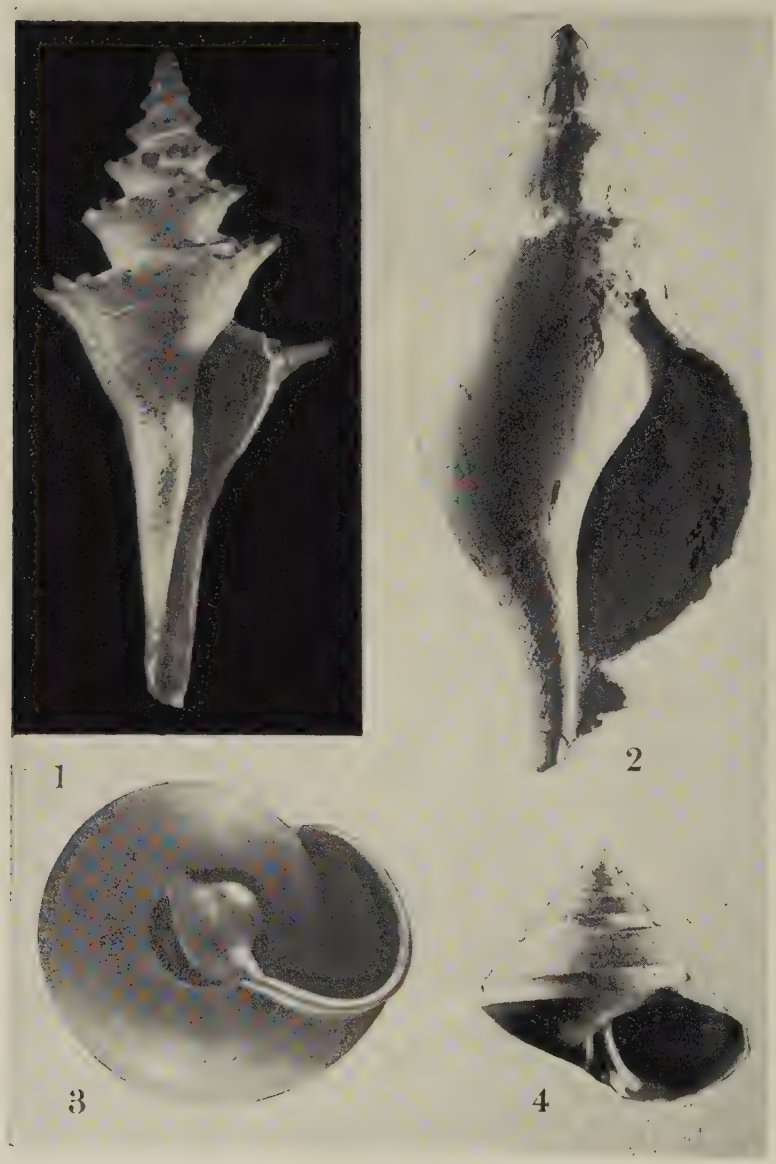

FIG. 1. – *Cochlespira* (*Ancistrosyrinx*) *radiata cubana* Cl. and Ag. Holotype. 4 ×.
„ 2. – *Bathyaurinia piratica* Cl. and Ag. Holotype. Nat. Size.
„ 3. – *Gaza superba cubana* Cl. and Ag. Holotype. 2 ×.
„ 4. – *Calliostoma atlantis* Cl. and Ag. Holotype. Nat. Size.

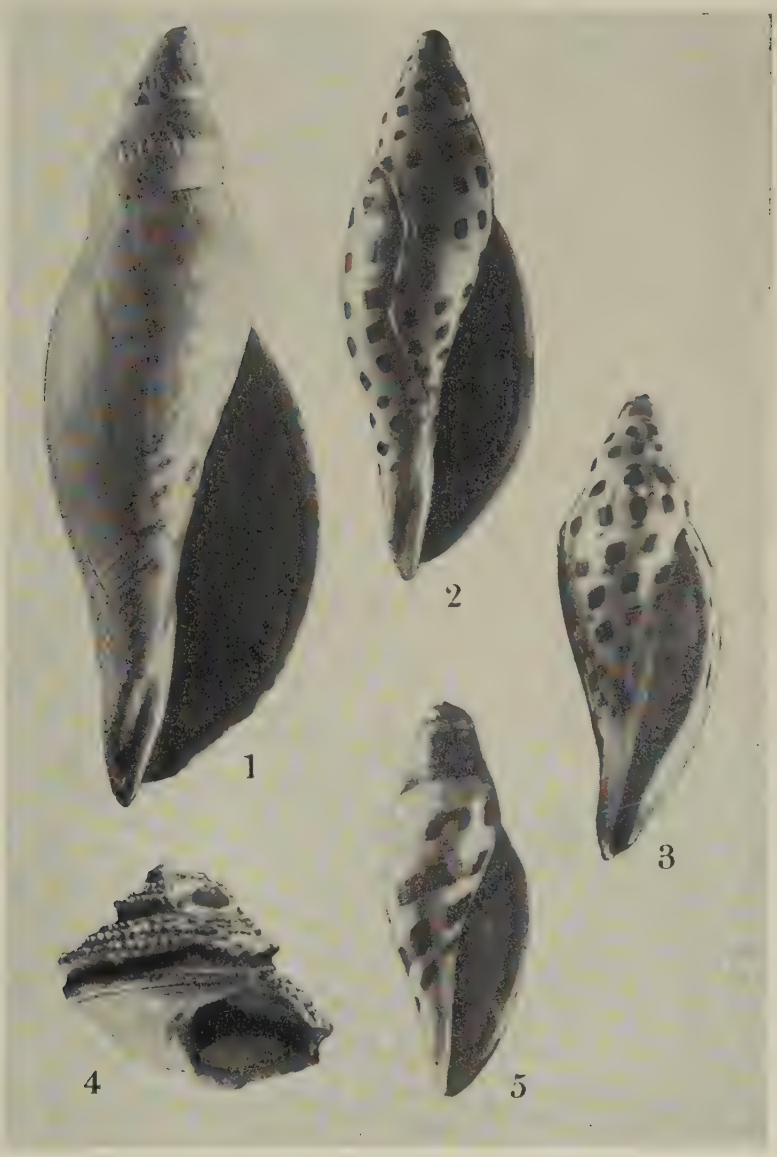

FIG. 1.—*Aurinia dohrni florida* Cl. and Ag. Nat. Size.
„ 2.—*Aurinia dohrni* Sowerby. Nat. Size.
„ 3.—*Aurinia bermudezi* Cl. and Ag. Holotype. Nat. Size.
„ 4.—*Calliostoma cubanum* Cl. and Ag. Holotype. 2 ×.
„ 5.—*Aurinia neptunea* Cl. and Ag. Holotype. Nat. Size.

Contribution No. 251

A DETAILED STUDY OF THE SURFACE LAYERS OF THE OCEAN IN THE NEIGHBORHOOD OF THE GULF STREAM WITH THE AID OF RAPID MEASURING HYDROGRAPHIC INSTRUMENTS

By

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INTRODUCTION

In an earlier communication in this Journal the writer reported on a Bathythermograph for obtaining continuous records of temperature against depth in the first 150 meters of the ocean (Spilhaus 1937). While further development of this preliminary instrument revealed it to be rather critical to vibration, the results obtained with it, some of which were reported in the paper cited above, were sufficient to indicate the desirability of further studies and development along these lines. Abrupt changes in the vertical temperature distribution with very small changes in horizontal distance together with extremely complex temperature structure in the vertical were observed in the surface layers. When an attempt was made to reproduce these instruments, various devices were employed in order to shield the bi-metal reed, which was then used as the temperature element, against the vibrational forces as it travelled through the sea water. While these could be reduced to a large extent when the instrument was used under favorable circumstances, it was not found possible to completely eliminate vibrations under all conditions because the bi-metal temperature strip formed an integral part of the recording stylus and had, necessarily, in order to reduce the transient errors in the record when the instrument passed rapidly through a thermoclime, to be exposed to the turbulent flow of the water through the instrument to insure adequate heat transfer to the temperature element. This incompatibility of the requirements was eliminated by the use of the bourdon type element where the bulb of the temperature responsive system may be exposed to the flow while the moving portion, the actual bourdon spiral, may be entirely shielded from flow. This is in essence the basic change made in the new Bathythermograph.

* Contribution No. 251 of the Woods Hole Oceanographic Institution.

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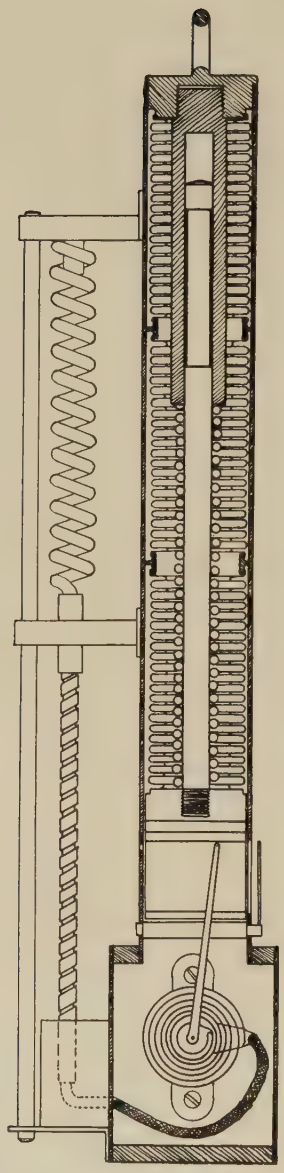

Figure 5. Diagram of Bourdon-type Bathythermograph.

DESCRIPTION OF THE BOURDON TYPE BATHYTHERMOGRAPH

The new Bathythermograph, incorporating the bourdon element described above, is shown in Figure 5. It will be seen that the instrument consists of a pressure responsive element which carries a holder into which a small glass slide may be slipped while the temperature responsive unit is fixed in the body of the instrument so that the slide, which receives the record, is moved parallel to the length of the instrument by pressure changes while temperature changes move the pen across the slide. Thus a plot of temperature against pressure is obtained on the glass. The slide is prepared for receiving the record in an identical fashion to that described by the writer (Spilhaus 1937). Figure 6 shows a photograph of the instrument, together with a box of records, the latter indicating the convenience of the small slides, for, when measurements are made in rapid succession, many hundreds of records may be taken on a single cruise. It may be noticed in the photograph that a Nansen bottle clamp is used to fasten the Bathythermograph to the hydrographic winch wire. This clamp with its tripping mechanism is used also to provide a means whereby, when the instrument reaches the lowest point of the descent into the ocean, a messenger may be sent down the hydrographic wire in the usual fashion to take off the pen, preparatory to the ascent of the instrument, so that only one trace, that of the descent, is obtained. In the case of the Bathythermograph soundings when the vesssel is not moving relative to the water and when the tem-

perature conditions are steady there is considerable value of having both traces and insuring that the two traces correspond as this is an excellent check as to whether the instrument is working perfectly. However, where the instrument was used while under way at sea, it was found that the descent and ascent curve of the instrument might differ quite considerably, not due to imperfect functioning of the instrument but due to the fact that actual

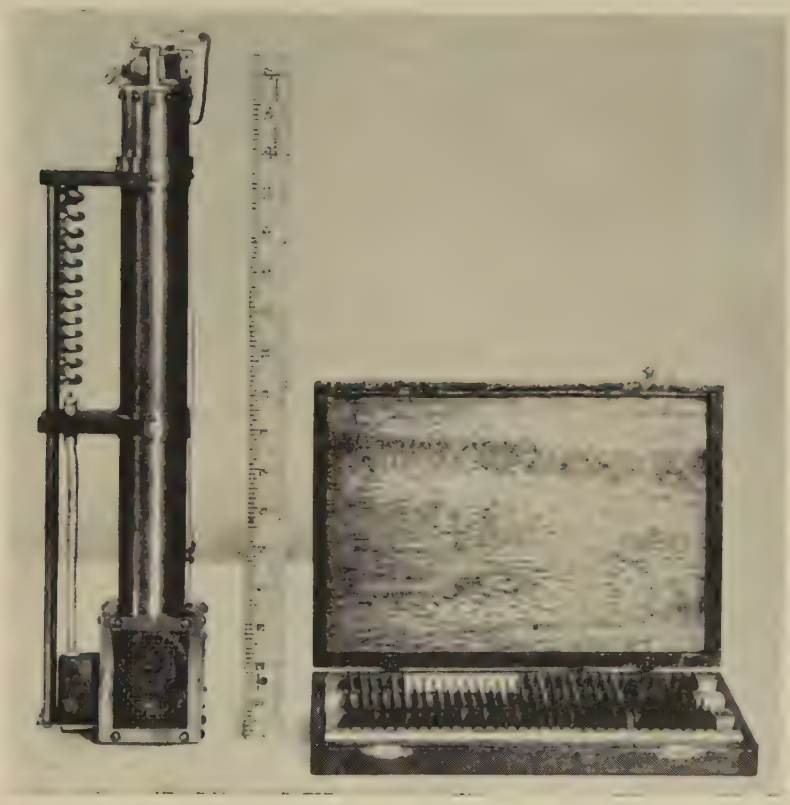

Figure 6. The Bourdon-type Bathythermograph and box of record slides.

horizontal gradients of temperature may be so great in the surface layers that considerable changes of temperature, level for level, are found due to the distance the ship has travelled in the interval between the time the instrument passed the particular level in its descent and the later time when it passed it again during the ascent. This is clearly brought out by examination of the later diagrams. The transient rate of the temperature element was found to be very rapid and certainly sufficient for all practical purposes. This high rate

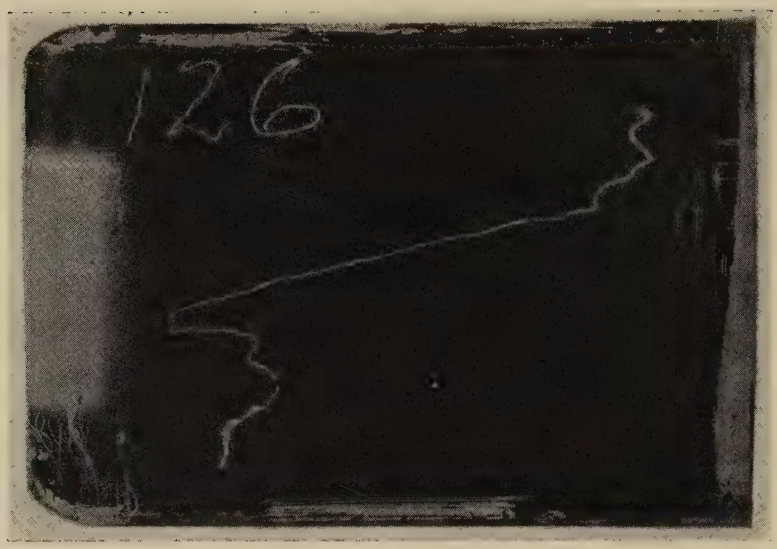

Figure 7. Enlargement of original record from Bathythermograph station No. 126.

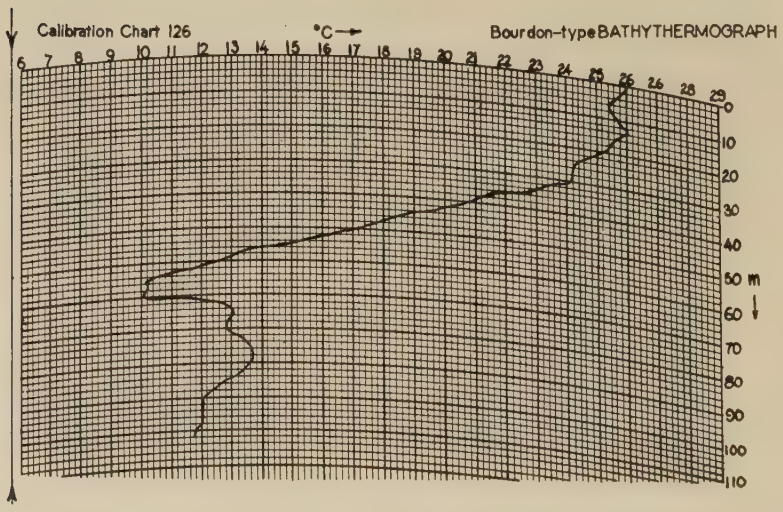

Figure 8. Same record as in figure 7 superimposed upon calibration chart.

of response was obtained by having the bulb constructed in helical form of a tube of small diameter, thereby obtaining a high surface-volume ratio. A typical trace is shown in Figure 7. Figure 8 shows the same trace superimposed on a calibration chart. The rise of temperature of about 3.0° Centigrade between 70 and 73 m. is noteworthy. The instrument was descending at that time at a rate of 20 meters per minute. In other words, this response took place in less than 10 seconds. Similar sharp inversions are observed very often on other records. The method of using the traces obtained on the small glass slides is very simple: a special projector throws an enlarged image of the trace on a frosted glass screen on which may be placed a translucent calibration chart. The graph of temperature against depth is then simply traced with pen or pencil onto the calibration chart. The slide holder in the projector is arranged to be in every respect similar to the holder in the Bathythermograph and, therefore, the slide is held in the same relative position in each. Thus, there is no need of any reference marks on the slide.

So completely did the use of the bourdon thermometer eliminate vibration that it was found the new Bathythermograph could be sent down into the ocean while the vessel was travelling at as high a speed as 11 knots. In fact, not the slightest vestige of vibration was apparent on a record made at this speed, the only difficulty experienced being that a considerable length of wire has to be paid out to get down to the requisite depth. This ability to use the Bathythermograph while travelling at high speed was very shortly recognized as a tremendous advantage because by this means a closer approach to synchronism of observations was made possible.

It was realized the value of the temperature depth soundings taken while under way would be greatly increased if it were possible to develop an instrument for taking salinities at the same time. The ideal solution, of course, would be the development of a recording salinity instrument whereby a continuous record of salinity against depth could be taken, preferably while the ship was in motion. However, the development of such an instrument, while entirely possible, will take some considerable time and it was felt that it is sufficient to have a continuous record of temperature and measurements of salinity at suitably distributed depths. This led to the development of a Sea Sampler for taking samples of the water at various predetermined depths while under way.

DESCRIPTION OF THE PRESSURE-OPERATED MULTIPLE SEA SAMPLER

The requirements to be met in the design of the Sea Sampler were, that wire angle must have no effect on the operation, that the instrument must take a number of samples at different depths and that the whole instrument should not be too bulky and clumsy in operation. The Pressure-operated

Multiple Sea Sampler comprising six sample bottles arranged such that they tripped at a distribution of points down to 150 meters was developed, and the experimental model was built for the writer through the kind cooperation of the Submarine Signal Company of Boston, Massachusetts.

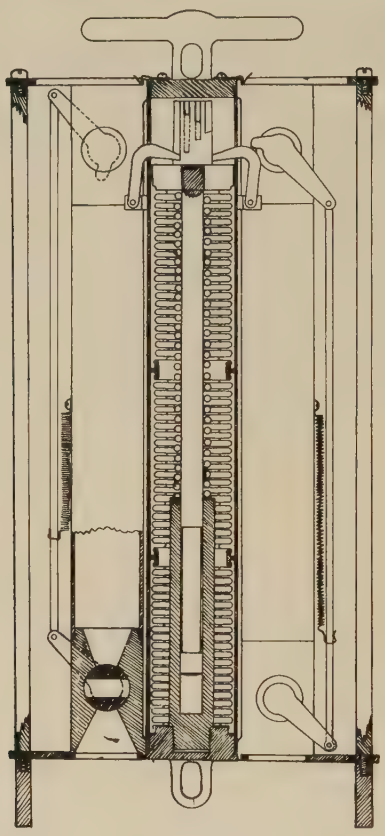

Figure 9. Diagram of Pressure-operated Multiple Sea Sampler.

A diagram showing the mechanism of the instrument is given in Figure 9 and a photograph of the completed instrument together with its carrying case and with two of the water bottles removed, is reproduced in Figure 10. Examination of these figures will show that essentially the instrument consists of a pressure responsive unit exactly similar to that used in the Bathythermograph which carries on its moving end a release controller which consists of a barrel with slots cut parallel to its axis. These slots are of dif-

ferent lengths and thus the trigger which presses on the barrel for each water bottle reaches the slot at a different pressure. Thus, each water bottle is released at a pressure which is determined by the length of the slot. Actually, in the instrument as built by the Submarine Signal Company, the release

Figure 10. The Pressure-operated Multiple Sea Sampler, showing two of the water bottles removed, and the carrying case.

controller is so constructed that the triggering points of the different bottles may be varied at will, so that a distribution of depths for the six water bottles may be chosen according to the particular data required in each case.

It should be possible to use the Pressure-operated Sea Sampler without stopping the vessel, although its bulk means that in all probability practical considerations will limit the speed of the vessel at which it can be lowered because its considerable drag will make it necessary to pay out a great length of wire in order to obtain the requisite depth. With the present Sea

Sampler, salinities have not been obtained while under way; however, this will be attempted directly the "Atlantis" is equipped with a hydrographic winch wire of sufficient strength so that there will be no danger of losing the instrument. In view of the fact that only one experimental model has been made, it has not been deemed advisable to risk the instrument on the regular hydrographic wire while the vessel is moving until a spare Sampler is available.

A considerable number of tests have been made with the Sea Sampler and these in general show slight differences in the Sea Sampler salinities from

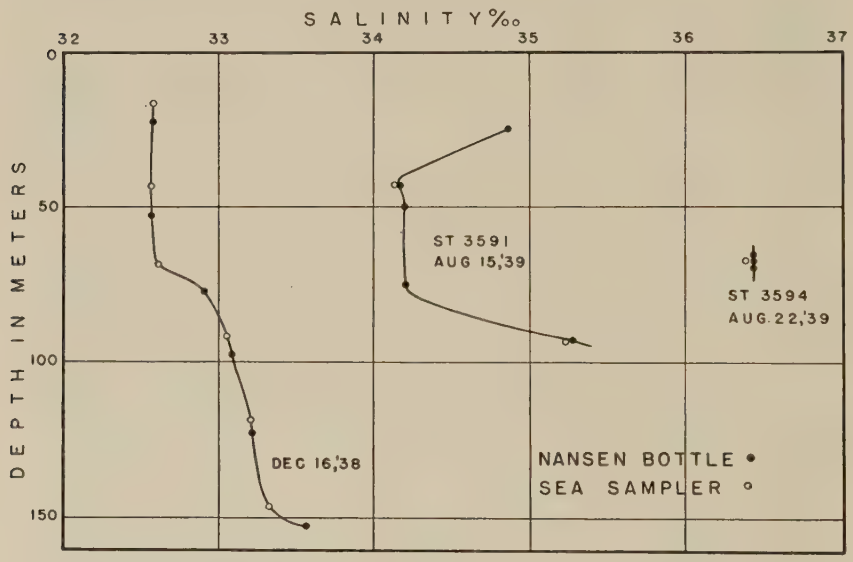

Figure 11. Comparisons between salinities obtained from Nansen Bottle samples and Sea Sampler specimens.

those obtained by the regular Nansen bottle technique. However, in many cases the differences may not immediately be ascribed to improper functioning of the Sampler, as it is extremely difficult to insure that the Nansen bottle trips at exactly the depth for which the Sea Sampler is set and it is, furthermore, extremely difficult to arrange that the two instruments take their samples at exactly the same time. Therefore, the differences observed in the tests may be due to the fact that the samples taken with the Nansen bottle were either taken not at the same depth or not at the same time, and both these factors may easily introduce real differences in the salinities of the order of magnitude found in the tests. In view of the fact that the Sampler is designed for use in the surface layers of the ocean where the salinity

variations are considerable, greater errors in the salinities can be tolerated than would be possible at greater depths. Figure 11 shows curves of salinity against depth for some of the comparisons made at various times. While the differences indicated are not smaller than the usually recognized allowable error, they are small enough so that pending further development of the Sampler the instrument is useful.

Tests made in the laboratory to determine the triggering points of the various sample bottles reveal a high degree of accuracy as far as the repetition of the release pressure is concerned. The following figures were obtained in the pressure chamber of the Submarine Signal Company:

Water Jar	*Release Pressure*	*Equiv. Depth*
1	24 lbs. per sq. in.	16.3 meters
2	63 lbs. per sq. in.	42.8 meters
3	101 lbs. per sq. in.	68.7 meters
4	135 lbs. per sq. in.	91.7 meters
5	174 lbs. per sq. in.	118.3 meters
6	215 lbs. per sq. in.	146.2 meters

Repetition of the test indicated that the release pressure never varied more than one pound from the release pressure indicated in the above table; that is, in general, the bottles will trip within plus or minus half a meter of the predetermined depth. Tests at sea in conditions where the wire angle was entirely negligible also revealed a tripping accuracy well within the accuracy of the meter wheel. It is for this reason that confidence may be placed on the fundamental principle of the Pressure-operated Sea Sampler but it is realized that further development is required. Particularly is investigation required of the degree to which throttling at the stopcocks of the sample bottles is effective in slowing up the exchange of water within the bottles and thereby causing a lag effect on the indicated salinities. For the purpose of studying this throttling effect, two small water bottles were constructed such that the body of the bottles was of the same cross section as the opening in the stopcock. It was thought that this would reduce the throttling effect. It is surprising, however, to note that all samples obtained by means of these smaller bottles were in far greater error than those obtained with the large bottles, and this would indicate that the erroneous readings are due to contamination of the sample rather than the throttling effect, because such contamination, whether it be due to leakage at the stopcocks or the introduction of water of different salinity by some other means, will have a greater effect the smaller the sample taken.

RESULTS OF TWO CRUISES WITH THE RAPID MEASURING HYDROGRAPHIC INSTRUMENTS

During the summer of 1939 two cruises of the "Atlantis" were carried out on which the instruments described above were used. On the first cruise in July, the Sea Sampler did not operate with sufficient regularity to permit it to be used for actually obtaining useful data. The functioning was impaired by the fact that spring tension to bring the trigger out again after its depression into the release controller was insufficient and on most bottles the triggers were thus broken off during the ascent of the Sampler. As no facilities for the repairing of these triggers were available on board the instrument could not be used on the remainder of the cruise.

The Bathythermograph operated extremely satisfactorily and a continuous section for a distance of 175 miles was made with a single break of 30 miles in which no records were taken. During this stretch of 175 miles, 51 records were taken, that is, with the exception of the 30 mile break, a record on an average for every three miles. Most of the time during this section the "Atlantis" was travelling at a speed of about 7 knots, although on certain occasions the speed increased to as high as 11 knots. No trouble was experienced in using the Bathythermograph at such increased speeds beyond the necessity of paying out more wire in order to counteract the increase of wire angle. The procedure adopted in working a continuous section with the Bathythermograph is to lower the weight, about 120 lbs. of lead, into the water and keep it in the water, then to attach the Bathythermograph to the hydrographic wire at deck level so that the insertion and removal of slides may be accomplished without removing the instrument from the wire. After the slide is inserted the Bathythermograph is lowered at full speed into the water. Approximately 400 meters of wire must be paid out in order that the instrument may descend to 120 meters depth when the vessel is travelling at 7 knots.

The course of both cruises on which the Bathythermograph was used is shown on Figure 12. The line entered between Atlantis station No. 3562 and continuing beyond Atlantis station No. 3565, indicates the position of the first Bathythermograph section. The continuous section is represented in Figure 13 in the form of a diagram showing the isotherms down to a depth of 120 meters for a portion of this course.* Only 60 miles of the section is shown in Figure 13. The remaining parts of the section indicated a very regular horizontal distribution of the isotherms in both the tests made before Station 6 and those made after Station 28, so that they have not been included in the figure. The distribution of the isotherms, however, in Figure 13 reveals features of extreme interest; the boundary of the Gulf Stream proper is situated approximately at Station 11 on this diagram and

* c. f. Fig. 12 for position of the portion of the course analyzed in Fig. 13.

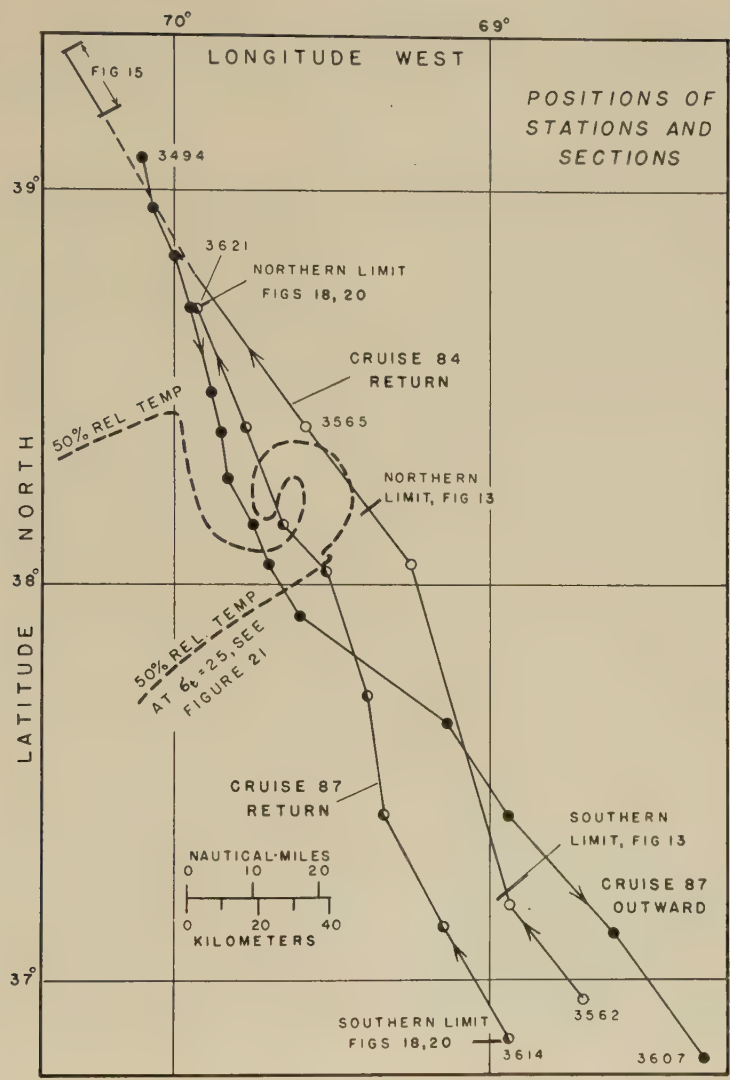

Figure 12. Chart showing positions of stations and sections. On the return route of cruise 84, full line indicates continuous Bathythermograph operation. Routine hydrographic stations marked by open circles. On the outward route of cruise 87 only routine hydrographic stations were made, as indicated by black dots. On the return route of cruise 87, full line indicates continuous operation of Bathythermograph, with Multiple Sea Sampler stations shown by black and white semicircles. Broken line indicates approximate course of 50% relative temperature boundary as shown in Figure 21.

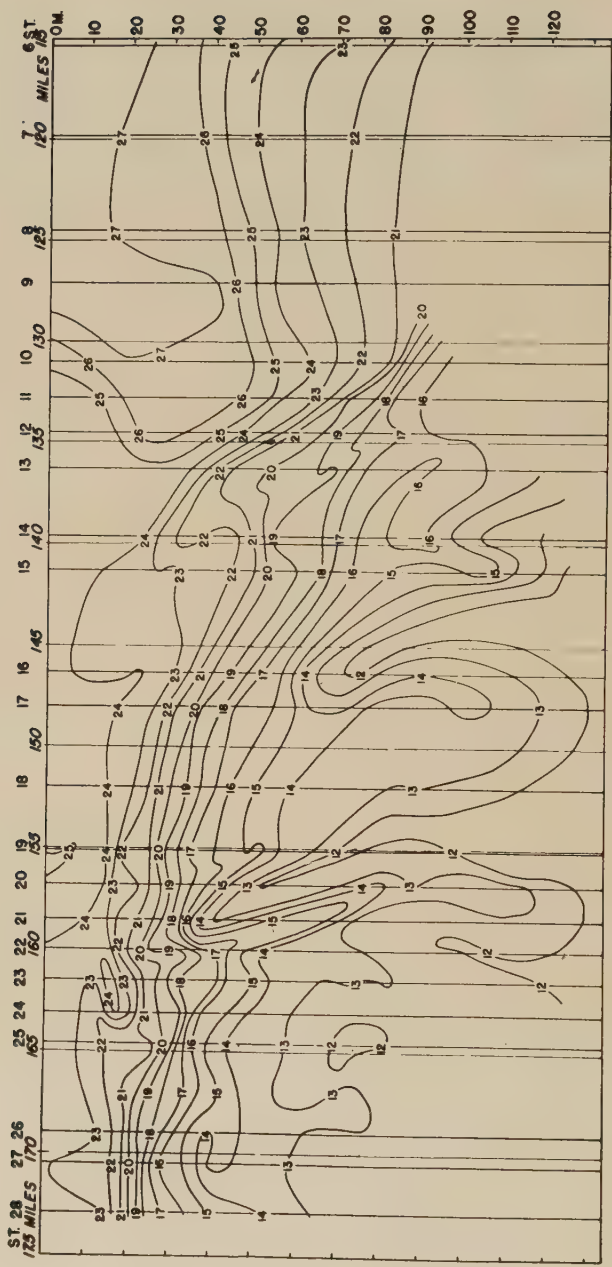

Figure 13. Distribution of isotherms in the surface layer in the neighborhood of the northwestern edge of the Gulf Stream (Cruise No. 84, July 1939).

it is in the water to the left of this point (looking down stream) that the isotherms are most disturbed. The 14° isotherm, for instance, exhibits in a 12 mile horizontal distance, between Stations 16 and 21, a variation from a depth of 65 meters at Station 16 to 110 meters at Station 17 and rising

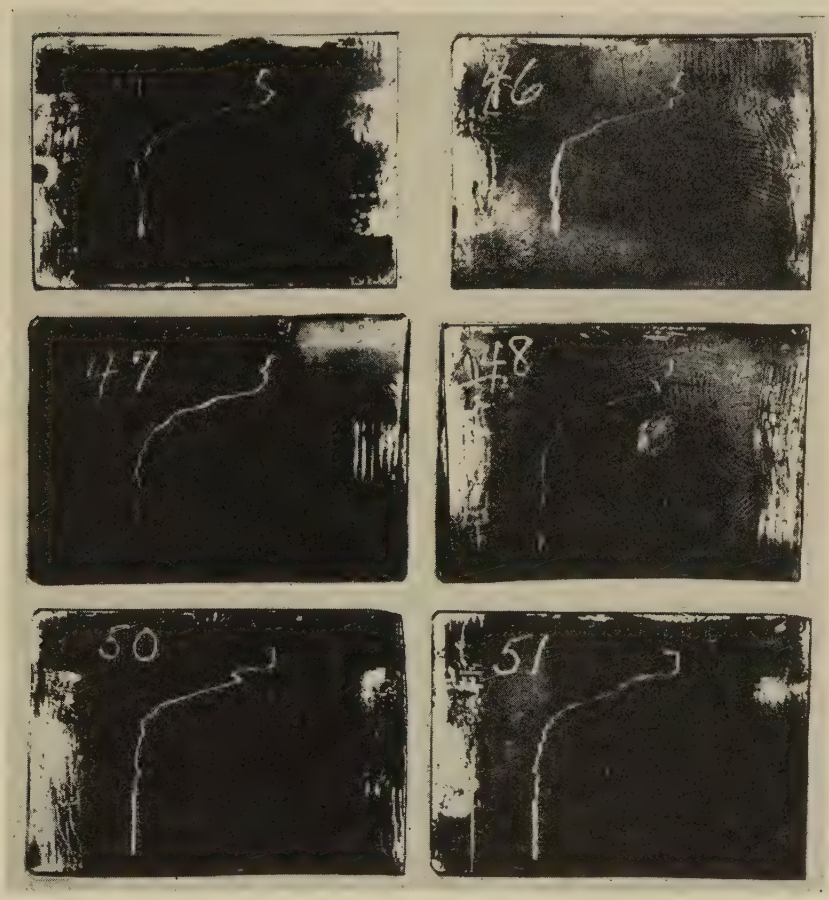

Figure 14. Some of the original records from which the data for figure 15 were obtained.

to a depth of only 40 meters in Station 21. These perturbations suggest the presence of a small eddy of the order of magnitude of 10 to 15 miles in size. Furthermore, from a knowledge of the general configuration of the isopycnals in these layers at the edge of the stream as given, for instance, in Figure 26 of Iselin's "Study of the Circulation of the Western North Atlantic,"

(Iselin 1936) it would seem that the shallower points of the 14° isotherm would lie along one ispycnal while the deeper points would fall along a different isopycnal, indicating that the water at the various shallower points was of the same origin (slope water) and that of the various deeper points of a different origin (Gulf Stream water). Because no salinities were taken simultaneously with the Bathythermograph soundings, it is not possible to

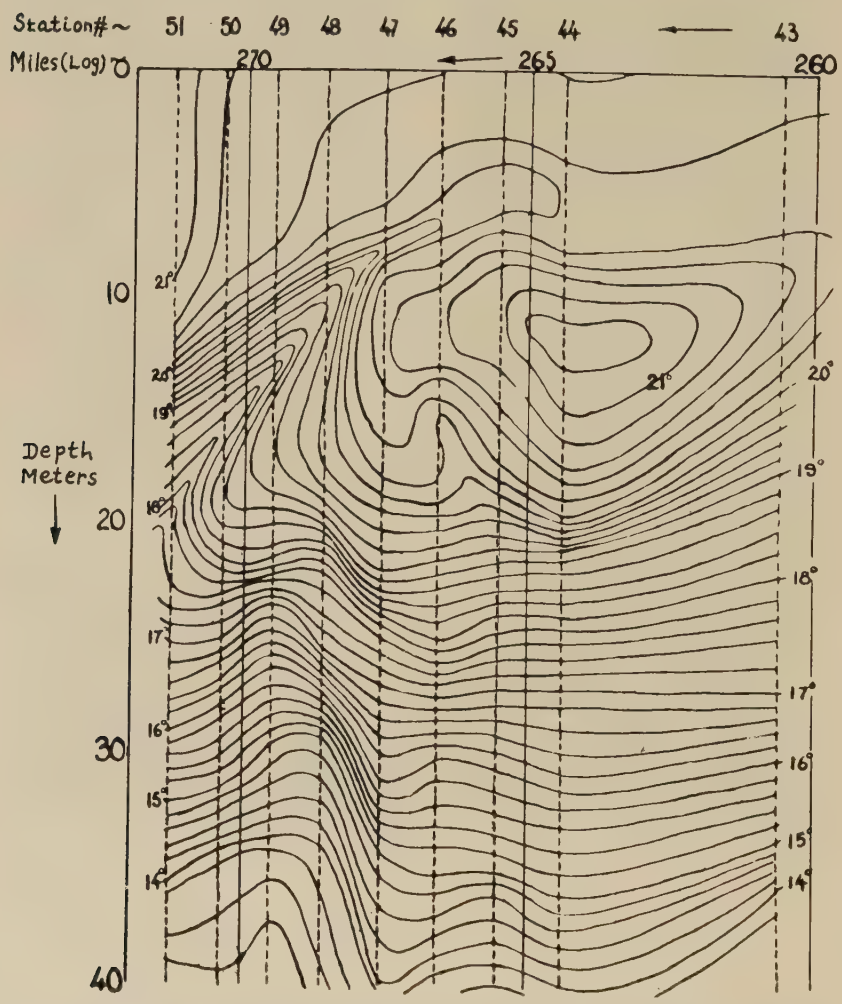

Figure 15. Distribution of isotherms in a short section (see Fig. 12), showing in detail the structure of a discontinuity zone in the surface layers.

establish the positions of the isopycnals in this particular case. On the second cruise densities were taken with the Sea Sampler and the above conclusion was ratified. This will be shown later.

A small section extending for a distance of 10 miles was made 30 miles to the north-west of the end of the continuous Bathythermograph section described above; the position of this section is shown in Figure 12 starting at Long. W. 70° 15′ and Lat. N. 39° 15′ approximately, and in this case Bathythermograph slide, No. 43, indicated a surface inversion of temperature starting at a depth of approximately 10 meters the highest temperature being recorded at about 13 meters. Similar surface inversions have been observed before, but not adequately explained. Therefore, directly this inversion was noted the Bathythermograph was operated rapidly and continuously so that for a 7 mile stretch records were obtained at intervals of less than a mile. Thus a very detailed analysis of this surface inversion could be made. The records are reproduced in their original form in Figure 14 and the inversion under scrutiny is that which occurs in the layer immediately over the summer thermocline. The nature of the inversion becomes clear when a detailed diagram of the isotherms in the first 40 meters is plotted. This diagram is shown in Figure 15, and it is likely that the inversion marks a sloping zone of discontinuity between the two water masses of slightly different characteristics. If, as is probable, although it cannot be proved in the present case as no salinities were taken, the sloping zone of discontinuity is bounded by surfaces of constant density, then Figure 15 provides an interesting pictorial representation of a "Margules slope" in the ocean.

Results of the Second Cruise.—After the Sea Sampler had been repaired and improvements incorporated to ensure its satisfactory operation, a second cruise was undertaken on the "Atlantis" with these instruments in August, 1939. The routine part of the cruise was to make one of the regular Gulf Stream sections as part of the Woods Hole program in connection with the Gulf Stream investigation. It was arranged, however, that on the return course of the vessel no stops would be made so that a continuous semi-synchronous section could be obtained with the Bathythermograph once more. Furthermore, provision was made to take water samples with the Pressure-operated Multiple Sea Sampler at intervals spaced further apart than the Bathythermograph stations but nevertheless close enough so that the distribution of isopycnals could be obtained. In Figure 12 the course of the second cruise is shown, and it is seen that the section is not far removed from the previous one and so it was to be expected that, if the small scale eddy observed at the edge of the Gulf Stream on the previous cruise and indicated by the disturbance of the isotherms in Figure 13 were real, it would be repeated in this case.

Figure 16 shows a plot of the isotherms for the cross section made by

Figure 16. Distribution of the isotherms as determined by reversing thermometers on the Montauk Point to Bermuda section. Relative position of Bathythermograph section given in Figure 17 shown by rectangle in broken lines between stations 3597 and 3604 (Cruise No. 87, August 1939).

means of the regular hydrographic technique on the outgoing course of the vessel. An extremely well developed, large eddy is present on this occasion and this would imply that there is a high rate of shear and therefore an even better chance for the development of small scale eddies in the neighborhood of the edge of the Stream. The position of the Bathythermograph section is indicated by the dotted rectangle extending horizontally from station 3597 past station 3603 and down to a depth of approximately 120 meters. This section is shown in the detail revealed by the Bathythermograph analysis made on the return in Figure 17, and a similar temperature structure to that obtained in the previous Bathythermograph section is again found. Furthermore, just as in the case of the section shown in Figure 13, the shallower positions of any one isotherm appear to lie along a line which would correspond to an isopycnal and the deeper positions along another ispycnal. However, in this case, with the aid of the salinities obtained by the Pressure-operated Multiple Sea Sampler, the actual isopycnals may be plotted and these are shown in Figure 18.

The distribution of the isopycnals obtained by the new rapid measuring instruments and shown in Figure 18, may be compared with those obtained on the outgoing section by the regular hydrographic technique and shown in Figure 19. The general configuration of the isopycnals is identical although the absolute depth at which any one density occurs is not the same on the two occasions. It is entirely possible that such changes could occur in the intervening few days between the outgoing stations in this region and the incoming ones.

The spacing of the stations at which samples were taken for salinity determinations and, therefore, for which the depth of the isopycnals may be computed was not as close as the spacing of the Bathythermograph stations. It therefore might seem that in drawing the course of the isopycnals in Figure 18 and also in Figure 19, the latter from densities obtained by the regular hydrographic technique, considerable smoothing has been carried out and that actually the isopycnals may wander in between the points at which salinity was determined. Unless very short intervals are made between the Sea Sampler stations, no definite evidence to prove conclusively that the isopycnals do not wander can be obtained. In a recent study (Seiwell 1939) the assumption has been made that the changes in depths of the isotherms are entirely due to changes in depth of the isopycnals, where here the assumption made is exactly the reverse, in other words, that changes in depth of the isotherms are due entirely to changes in the temperature salinity correlation. It is probable that neither of these extremes is entirely permissible. Seiwell's analysis, however, was for much deeper layers than the present one and indirect evidence in our case would indicate that the assumption made here is valid. For instance, the comparison of Figure 18 with Figure 19 which reveals an identical general configuration of the iso-

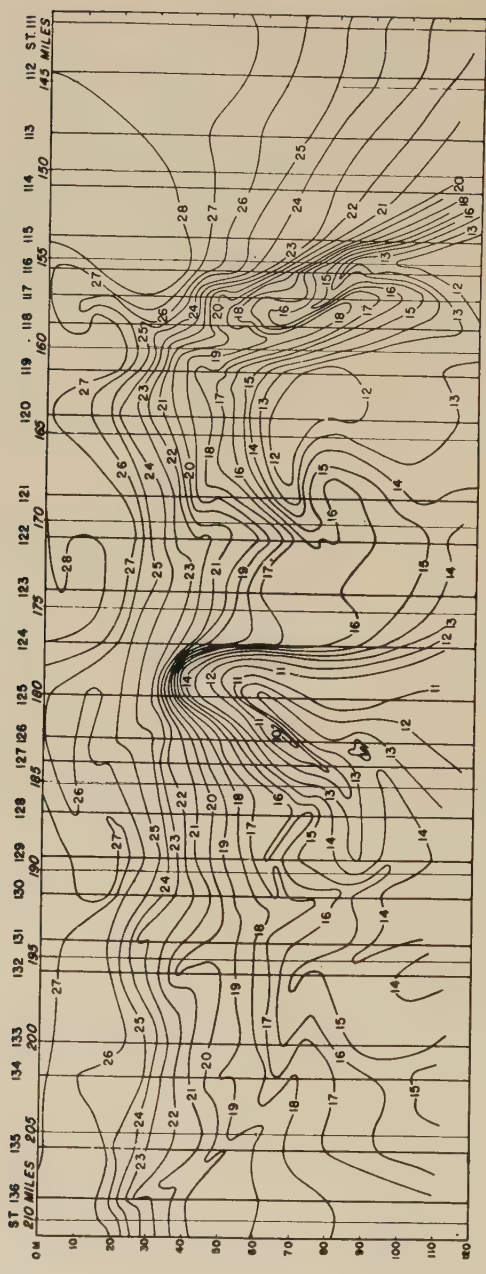

Figure 17. Distribution of isotherms in the surface layers in the neighborhood of the northwestern edge of the Gulf Stream as shown by Bathythermograph records (Cruise No. 87, August 1939).

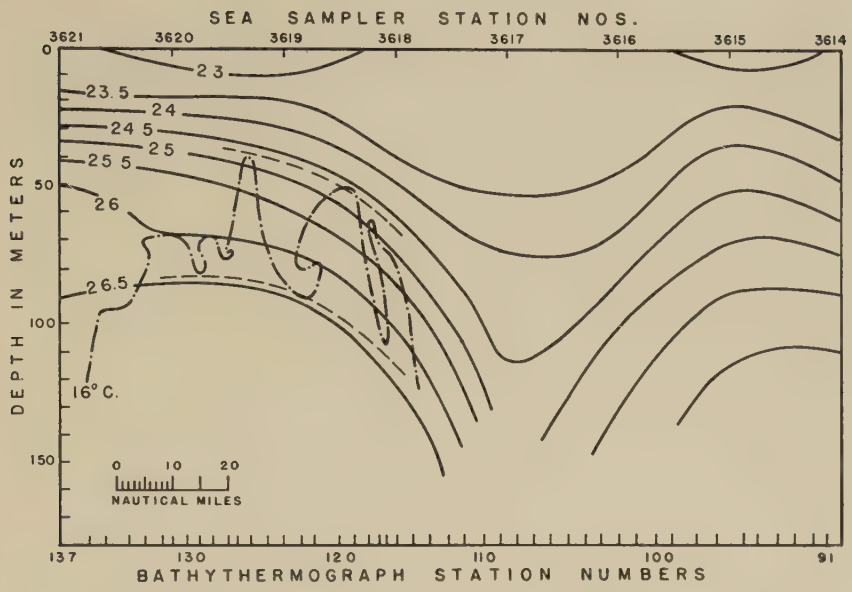

Figure 18. Distribution of isopycnals and 16° isotherm from Bathythermograph and Sea Sampler data.

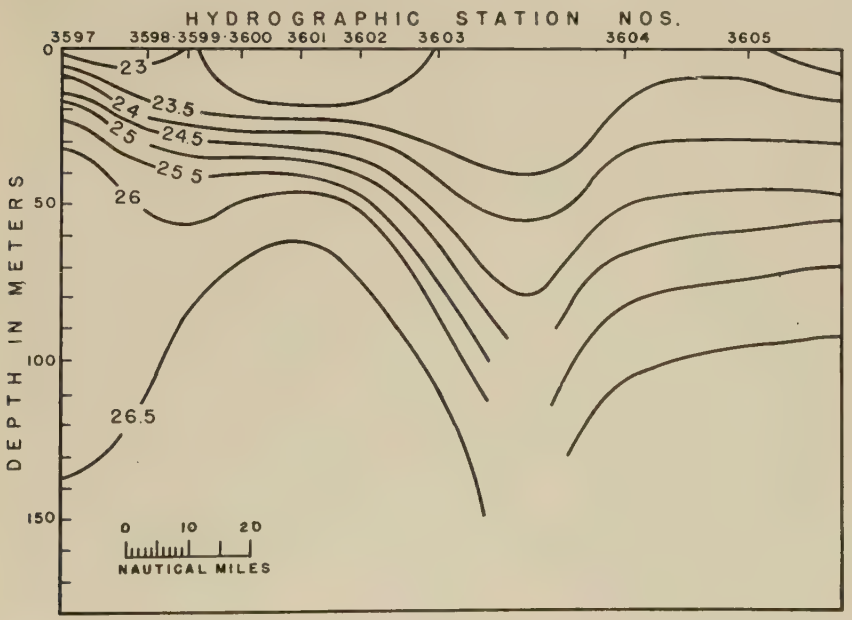

Figure 19. Distribution of isopycnals according to observations from routine hydrographic stations.

pycnals on the outgoing and incoming parts of the cruise must be accepted as rather good evidence that there is no small scale distortion of the isopycnals, especially in view of the fact that on the outgoing part of the cruise, regular hydrographic stations were made at extremely short intervals; the part of this section, which corresponds to that region where the complex temperature structure is observed on the return part of the cruise, lies between "Atlantis" stations 3598 and 3603 and here six hydrographic stations were made in a distance of about 50 miles. Even with the stations as close as this the isopycnals are very smooth and regular (c. f. Figure 19). Furthermore, if the data is examined from sea sampler stations 3618 and 3619 (corresponding Bathythermograph station 116 and 123 respectively) by comparing the salinity at the 15° Isotherm for example, the following result is found:—

Bathythermograph Station No.	*Sea Sampler Station No.*	*Salinity °/₀₀ at the Depth of the 15° C. Isotherm*	*Depth of the 15° C. Isotherm Meters*
116	3618	34.60	77
123	3619	35.97	102

This shows an extremely marked change in the T-S correlation which is in agreement with our assumption of a relatively smooth distribution of density.

In order to test the suggestion made above regarding the relation of the isotherms to the isopycnal surfaces the 16° isotherm has been sketched in on Figure 19. It is immediately seen that the wanderings of the isotherm in the vertical occur definitely in a layer enclosed by two surfaces of constant density. The 16° isotherm is chosen arbitrarily as an example, though others for other values of the temperature will reveal the same feature. It has been frequently emphasized in oceanography that reliance on the temperature salinity correlation is not justified in the surface layers of the ocean. While it is quite true that there will be departures from the temperature salinity correlation due to surface heating and evaporation effects, in the opinion of the author it is in all probability the presence of small eddies and the consequent lateral mixing which principally upset temperature salinity correlations in the surface layers. Therefore, a method involving temperature salinity correlation will reveal the presence of these eddies if the station spacing is less than the dimensions of the eddy. An analysis was made following the suggestion of Professor A. E. Parr (Parr 1938) to use relative values of the identifying property along isopycnal surfaces. Parr chose to use relative salinity as his identifying value but in view of the fact that in the case of the new rapid measuring technique continuous records of temperature are available it is preferable here to use relative temperature. Obviously, in view of the fact that density is a function of temperature and

salinity, either temperature or salinity on an isopycnal is perfectly suitable for such identification. Therefore, values of the relative temperature obtained in exactly the manner outlined by Parr were worked out and in Figure 20 iso-lines of the 50% relative temperature values have been drawn. These give an indication of the division of the tongues of slope water and tongues of Gulf Stream water, the former with relative temperatures less than 50%, the latter greater than 50%. The figure shows in a

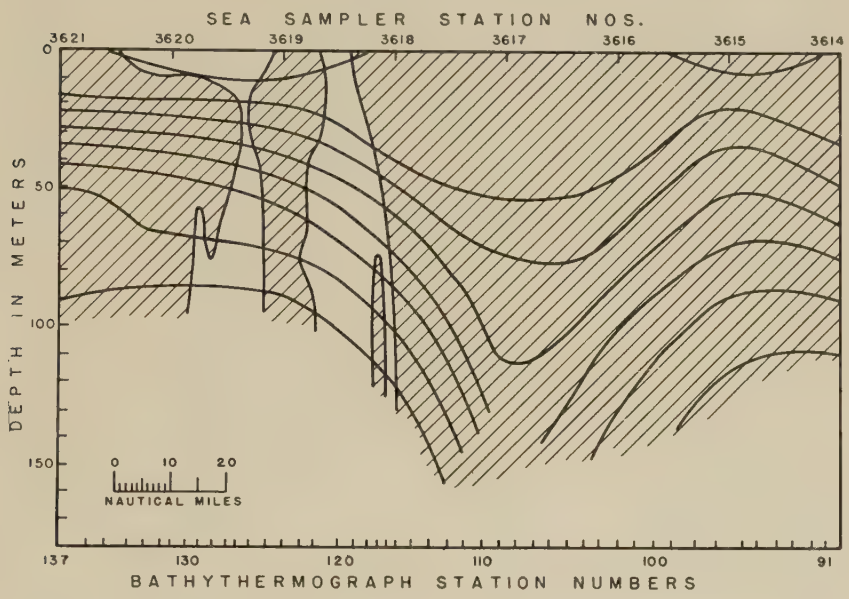

Figure 20. Distribution of relative temperatures in section shown in Figure 18. Relative temperatures above 50% indicated by hatched areas, below 50% by blank regions.

very remarkable fashion that the intrusion of slope water is in the form of a tongue which extends to depths without much lateral displacement.

While explicit conclusions regarding the nature of the eddy (its direction and rotation etc.), which in cross section would give this distribution of relative temperatures, may not be drawn from a single section, it may be shown that a formalized and entirely logical eddy formation will fit the available data. Thus in Figure 21 the temperatures along the surface of $\sigma_T = 25$ are plotted, and a series of isotherms, representing a reasonable eddy formation, are drawn in which satisfy the data. An extremely interesting feature on this diagram is the appearance of a parasite eddy on the right side of the cold tongue. This parasite eddy was indicated on the cross

section on Figure 20. Referring to this figure, it will be seen that there is at Station 117 a small intrusion in warm water for which the 50% relative temperature extends to a depth of 85 meters. Furthermore, on Figure 20 there appears to be a second parasite eddy at Station 129. This second

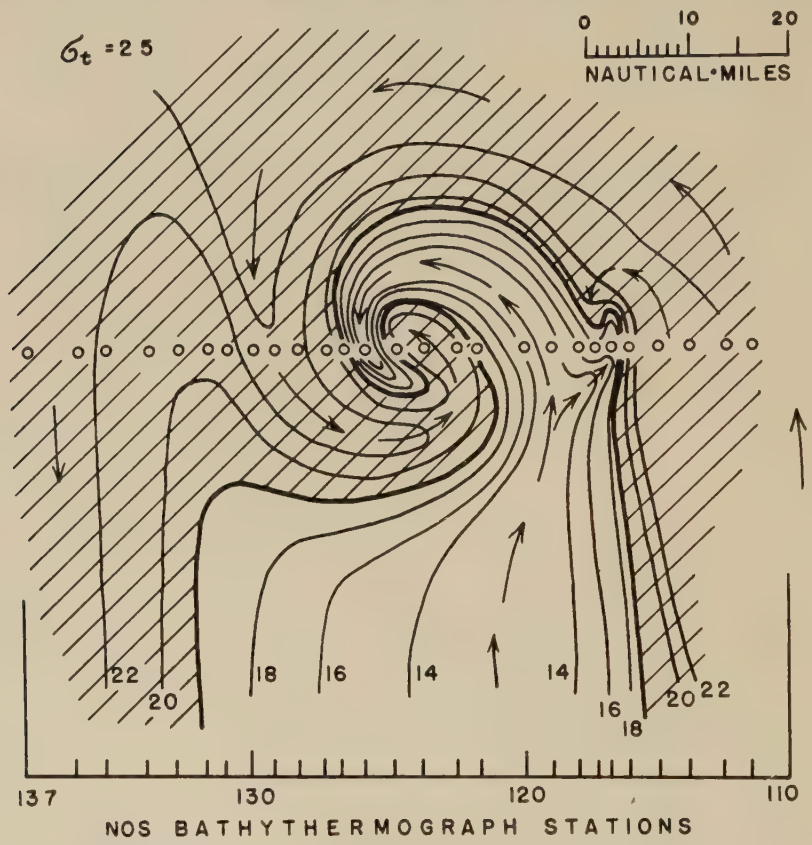

Figure 21. Eddy of intermediate size with parasite drawn to conform with temperature distribution on the isopycnal surface of $\sigma_T = 25$ (somewhat diagrammatical).

parasite on the left side of the cold tongue is not shown up on the surface of $\sigma_T = 25$ but it appears on a similar diagram for $\sigma_T = 26$. Perhaps the appearance of these parasite eddies is one of the most interesting features brought out by this analysis. While they are in no sense incontrovertibly established by the present data and must to a large extent be regarded as speculation on the part of the writer, it is believed that they must exist in

any such eddy formation. Also, the data, such as it is, lends support to the belief in their existence. In all probability, many more parasite eddies would be found on the tongue if a great number of sections were taken so that a well distributed field of temperatures could be plotted on the surface.

It is interesting to observe that in this particular case we have quite clear indications of three distinctly different sizes of eddies. First, the large scale eddy which is shown up by the distortion of the isotherms down to considerable depths as indicated in Figure 16. By the data obtained with the routine hydrographic technique the dimension of this eddy measured as the distance between the axes of the dissimilar tongues, is of the order of magnitude of about 150 kilometers. Secondly, we have the intermediate eddy shown on Figure 21 with a corresponding dimension of about 30 kilometers and, thirdly, the parasite eddies with a dimension of the order of magnitude of 5 kilometers. The intermediate size is of the same order of magnitude as Dr. Rossby's estimate on the basis of a shear of 10^{-5} sec.$^{-1}$ (Rossby 1938), and this would indicate that eddies of these dimensions are numerous enough for their effect on large scale phenomena to be capable of statistical treatment.

PROJECTED OPERATIONS WITH THE RAPID MEASURING INSTRUMENTS

The foregoing preliminary analysis has demonstrated that it is of extreme interest to obtain detailed analyses of the surface layers of the ocean. It is proposed to extend this type of investigation so that either by the cooperation of more than one ship, each equipped with a Bathythermograph and Sea Sampler, or by zig-zagging over the region to be studied, a distribution of points in the isopycnal surface taken semi-synchronously may be obtained. This will enable confirmation of the eddy patterns outlined above to be obtained by an analysis of the type employed by Montgomery (1938).

It is further proposed that after development of the individual mechanisms of the Bathythermograph and Sea Sampler is progressed to a satisfactory point they may be combined such that the same pressure element will be used to trip the Sea Sampler water bottles and also to carry the slide of the Bathythermograph unit. The desirability of making temperature and salinity measurements at exactly the same point even though the position of this point is not so accurately known, has been stressed by Dr. Montgomery and such a combination of the two instruments will insure that the temperature at which salinity sample was taken is accurately known. The proposed combination is illustrated in the diagram Figure 22. It is believed that when each water bottle trips there will be a sufficient jar to the instrument so that the recording stylus of the thermal unit will make

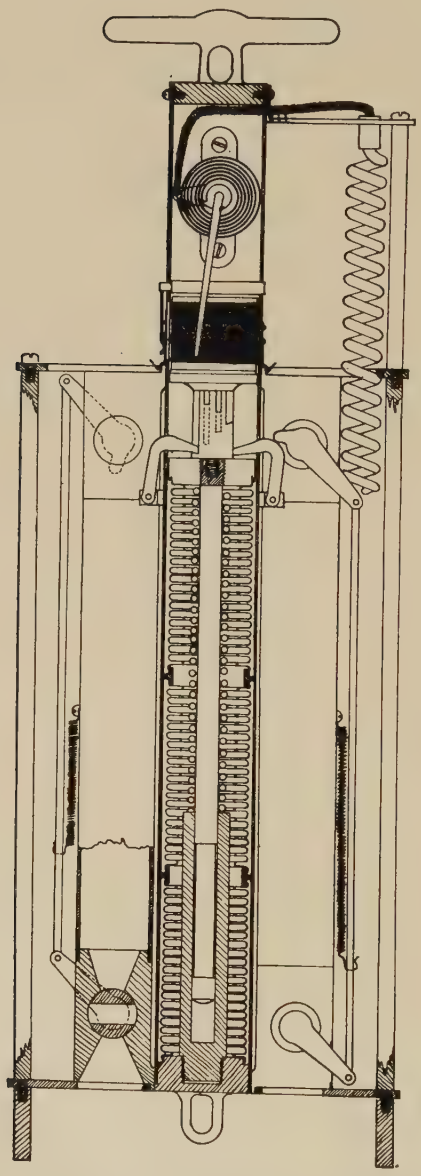

Figure 22. Diagram of proposed combined Bathythermograph and Pressure-operated Sea Sampler.

a noticeable mark on the temperature depth trace. This will be valuable, in addition, for establishing exactly the point of tripping. If it is found that jar caused by the water bottle tripping is insufficient to make such a mark, a simple mechanism is contemplated which will accomplish this.

Such investigations as these, where a complete change in the characteristics of the water may be expected to take place within a distance of a few miles, necessitate fixing the relative positions of the Bathythermograph stations very exactly. In the case of the data described above, the sections plotted for the Bathythermograph are plotted on a horizontal scale representing the reading of the ship's log, that is the distance relative to the water. However, if more than one section is taken the relative positions of the different sections will have to be obtained exactly. If more than one vessel is employed, range finders to obtain relative positions would be very valuable.

In conclusion the writer wishes to express his indebtedness to the Submarine Signal Company of Boston, Massachusetts, who undertook the construction of the instruments described above and without whose assistance the investigation would hardly have been possible.

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A New Record of Two Flounders, *Etropus crossotus* Goode and Bean and *Ancylopsetta dilecta* (Goode and Bean), With Notes on Postlarval Characters[1]

By SIDNEY C. T. HSIAO[2]

THE research ketch "Atlantis" of the Woods Hole Oceanographic Institution caught fifteen postlarval *Etropus crossotus* and two postlarval *Ancylopsetta dilecta* by oblique hauls made by a 2 meter open stramin net along the outer slope of Georges Bank, September 7-12, 1939. These postlarval Paralichthinae were found at four stations two of which are on the southern slope of the eastern tip of Georges Bank (about 41° N., 66° W.) and the other two also on the southern slope but about 180 nautical miles to the southwest. At the shallower stations the stramin net was drawn from a point near the bottom up to the surface, while at the deeper stations it was drawn through the top 160 meter layer only. The specimens were taken in hauls made during morning, afternoon and midnight.

The collections represent a more northerly and easterly record than has been reported heretofore for these two species. On this side of the American coast *E. crossotus* occurs between Chesapeake Bay and the West Indies and *A. dilecta* is found off the coast of Carolina. No adult of either species has been observed over Georges Bank or in the Gulf of Maine. The postlarval individuals caught off Georges Bank were most probably spawned further south and transported to this place by the Gulf Stream. It has been established that tropical forms actually come over the slope on to Georges Bank and further into the Gulf of Maine (compare Bigelow, 1924: 51–59). Our collections may be another case of "tropical visitors." If these flounders were spawned on the continental slope or over the shelf off the coast of Florida it would be a comparatively simple matter for the Gulf Stream to carry them northward to the Georges Bank region.

The specimens of *E. crossotus* ranged in total length[3] from 6.5 to 15 mm. From their small size it may be inferred that they had not drifted very long but were spawned sometime in late summer or early fall. The specimens of *A. dilecta* were probably spawned at about this same time, for their total length is only 8.0 to 8.2 mm.

As no newly metamorphosed or adult *Etropus* or *Ancylopsetta* has been reported inside the Gulf of Maine it is doubtful if the young of these species can survive the conditions within the Gulf.

A figure of the larval form of *E. rimosus* and one of a young specimen of *Notosema* (=*Ancylopsetta*) *dilecta* are given in *Oceanic Ichthyology* by Goode and Bean (1896). Except for these figures no drawing or description of the postlarval stages of American Paralichthinae belonging to these two

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[2] This work has been supported by a research fellowship from the China Foundation and carried out under the direction of Prof. H. B. Bigelow.

[3] The measurements and terms defined by Norman (1934: 50–51) as well as his classifications are followed in this paper.

genera has been published. The following descriptions based upon material preserved in formalin are made to fill this gap.

Etropus crossotus.—Postlarvae, less than 10 mm. in total length, corresponding to Kyle's (1913) early postlarval stage; whitish, almost transparent, with internal organs clearly visible, and so greatly compressed laterally as to become laminate. Dorsal body outline gently convex; upper profile of head slightly concave. Maxillary extending to anterior edge of eye. Larval teeth on both sides of both jaws. Vent nearer to the snout than to the base of caudal. Dorsal originating in front of eye, directly dorsal to the external nare on dextral side. "Dorsal tentacle" present (bifurcated in

Fig. 1. *Etropus crossotus,* total length 6.5 mm. Camera drawing from specimen stained with borax carmine.

our much handled material), much elongated, with maximum length about ⅓ the length of the fish. Dorsal 78-87; rays at beginning of the posterior half of body longer than the rest. Anal 59–65, originating from posterior margin of vent; rays at the posterior half of body longest. Ventral 6, midway between snout and vent. Air-bladder simple, transparent, between viscera and 7th to 10th vertebrae. Vertebrae 9 + 25. No pigmentation.

Individuals longer than 10 mm. in total length, corresponding to Kyle's late postlarval stage, translucent, "temporary characters" disappearing: air-bladder very small or absent, "dorsal tentacle" absent, but its base remaining.[4]

The classification of *Etropus* is in an unsatisfactory state (contrast the opinion of Jordan and Evermann, 1898; Bean, 1901; Parr, 1931; and Norman, 1934). By adopting Norman's classification and by comparing the

[4] The relative size of the different parts of the body, a less constant character, has not been included in this description.

radial formulae of our material with those found in literature on this group, we identify our specimens with *E. crossotus*.

Ancylopsetta dilecta.—Both specimens (8 mm. and 8.2 mm. in total length) symmetrical. Body slightly elongated. Dorsal curve gently convex, but abruptly concave in the interorbital region; ventral curve nearly straight except for a sharp upward bend immediately behind the vent. Vent midway between snout and base of caudal. Body region behind vent greatly compressed laterally; head and anterior region of trunk thicker. Greater part of body translucent. Maxillary extending to below middle of eye. Head bony in appearance. One spine standing out clearly in frontal view as a lateral

Fig. 2. *Ancylopsetta,* total length 8 mm. Camera drawing from specimen preserved in formalin, unstained.

projection on the sphenotic region immediately ventral to the anterior end of the dorsal, and at some distance above the eye. Four subequal bony triangular projections on ventral edge of preoperculum whose postero-ventral angle is adorned with a large, elongated, quadrangular process. Air-bladder large, transparent, pigmented on its dorsal side, between the abdominal vertebrae and viscera. Dorsal fin originating over anterior margin of eye on dextral side. continuing to the caudal near which the rays are not well differentiated; anterior 8 rays much elongated, nearly equal to each other. Of the other rays those at the beginning of the posterior half of trunk longest; dorsal more than 66. Anal more than 55; originating immediately behind vent; middle group of rays longest. Pectoral anterior to ventral. Ventral on sinistral (future ocular) side with 3 much elongated rays followed by 2 or 3 shorter ones; longest ventral slightly shorter than longest dorsal fin rays. The other ventral not elongated. Caudal 18, strongly double-truncate. Vertebrae 35. Pigmentation consisting of a system of 3 lines and 5 blotches. The

linear series run along (1) dorsal body edge, (2) posterior half of lateral line and (3) ventral body border. Dorsal line of pigment cells concentrated into groups at five points where the cells are larger and closer together than in the intervening space. Two similar groups along the lateral line and 3 along ventral body border. Five pigmented blotches occur (1) above the air-bladder, (2) on ventral side of basihyal, (3) on head below the first two bony processes of preoperculum, (4) between tips of branchiostegals and base of ventral and (5) between base of ventral and vent. Figure 2 shows the relative position of the pigment cells.

The drawing given by Goode and Bean (1896: fig. 362) shows a larger individual than our specimen. Unfortunately no size is given by these authors. In their specimen blotches of pigments are present over the interneural and interhaemal spines in association with each group of the dorsal and ventral chain respectively. The bony processes on the head are absent. The caudal has become pedunculate. All these indicate further development than in our material.

There are two species of Atlantic *Ancylopsetta: A. dilecta* and *A. quadrocellata.* In *A. quadrocellata* the ventral fin on the ocular side is not much more elongated than its fellow on the blind side and the anterior rays of the dorsal not so much elongated as in the other species. The elongation of the 8 anterior dorsal rays and of the sinistral ventral fin of our two specimens indicate that they belong to *A. dilecta.*

Summary

This paper makes a new record of the most northerly and easterly occurence of *Etropus crossotus* Goode and Bean and *Ancylopsetta dilecta* (Goode and Bean) based on collections of their postlarvae off Georges Bank. It also records that the probable breeding season of these two species of sinistral Paralichthinae is between late summer and early autumn. The diagnostic characters of the postlarval stages of these forms are described.

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Contribution No. 255

THE FAMILY ANTEDONIDAE IN THE WEST TROPICAL ATLANTIC*

BY AUSTIN H. CLARK

The family Antedonidae is represented in the western tropical Atlantic area by sixteen species distributed in eight genera. These eight genera fall into five subfamilies, Antedoninae, Thysanometrinae, Zenometrinae, Perometrinae and Bathymetrinae. Of the seven subfamilies of the Antedonidae only two are not represented, the Antarctic Isometrinae and the polar and east Pacific Heliometrinae.

Of the eight genera represented four (*Hybometra, Coccometra, Zenometra* and *Hypalometra*) are not known from elsewhere. Of the other four one (*Antedon*) is otherwise known from the northeastern Atlantic coasts and Iceland; one (*Compsometra*) is characteristic of the Indo-Malayan and Australian regions; one occurs (*Caryometra*) in the Maldive region; and the fourth (*Trichometra*) is cosmopolitan in deep water of rather high temperature, except in the eastern Pacific.

Regarding the species of Antedonidae in the western Atlantic a curious feature is that, except for two, all are of medium size; only *Zenometra columnaris* is large, and only *Trichometra minutissima* is small. Furthermore, they are all strikingly similar in superficial appearance. Their determination therefore requires more careful study than is the case with the much more obviously diverse species in the eastern tropics.

The outstanding feature of the *Atlantis* collection was the occurrence therein of five new species of the genus *Caryometra* hitherto known only from a single species in the Caribbean region and a second from the Maldive Islands.

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* Contribution No. 255 of the Woods Hole Oceanographic Institution.

All the species of *Caryometra* are superficially very much alike. It happens that in the subfamily Zenometrinae, to which *Caryometra* belongs, the spicules in the perisome of the pinnules present excellent systematic characters (see Bulletin 82, U. S. Nat. Mus., part 3, 1921, fig. 800, p. 378, *Zenometra columnaris*: fig. 801, p. 378, *Sarametra triserialis*; fig. 806, p. 378, *Eumorphometra concinna*; fig. 775, p. 362, *Poliometra prolixa;* and fig. 765, p. 362, *Eometra antarctica*). The spicules in the pinnules of each of the species of *Caryometra* are characteristic and appear to differ constantly and considerably from those in all the other species. They are all of the same general type as the corresponding spicules in the related genera *Poliometra* of the cold Arctic deeps and *Eometra* of the Antarctic.

The following key will serve to make clear the interrelationships of the west tropical Atlantic species of the family Antedonidae as we understand them at present.

KEY TO THE COMATULIDS OF THE FAMILY ANTEDONIDAE OCCURRING IN THE CARIBBEAN SEA AND ADJACENT WATERS

*a*1. Cirrus sockets without definite arrangement, closely crowded or scattered on a subdiscoidal to rounded conical centrodorsal which is usually broader at the base than high.

*b*1. P_1 composed of not more than 30 segments which, except for a very few proximal, are longer than broad and usually much elongated.

*c*1. Distal cirrus segments entirely without dorsal processes on their distal ends; cirri short with not more than 20 segments.

ANTEDONINAE.

*d*1. P_2 much shorter than P_1, resembling P_3.

*e*1. Pinnule segments with smooth distal ends; P_1 with 25-30 segments, twice as long as P_2; a small plate in each interradial angle between the IBr_1.

Antedon dübenii.

*e*2. Pinnule segments with strongly produced and spinous distal ends; P_1 with 18-20 segments, half again as long as P_2; no interradial plate between the IBr_1.

Compsometra nuttingi.

*d*2. P_1, P_2, and P_3 similar and of approximately the same length, slender and stiffened, composed of about 15 much elongated segments; P_3 is not longer than P_4.

Hybometra senta.

*c*2. Distal cirrus segments with the distal dorsal edge prominent, the dorsal line more or less carinate, and the middle of the dorsal edge more or less produced in the form of a spine.

*d*1. No pinnules on the second and fourth brachials.

Perometrinae: *Hypalometra defecta.*

*d*2. All the pinnules present; P_1 much elongated and filiform distally; IBr series and first two brachials only moderately convex dorsally and broadly flattened laterally against their neighbors.

Bathymetrinae.

*e*1. Cirri with 25-30 segments, 15-22 mm. long; arms 45-65 mm. long.

Trichometra cubensis.

*e*2. Cirri with 12-15 greatly elongated segments, 4 mm. long; arms 13 mm. long.

Trichometra minutissima.

*b*2. P_1 composed of very numerous (usually more than 50 and never less than 30) short segments of which at least the first 6 or 7, and usually nearly all, are broader than long and the terminal are rarely more than twice as long as broad.

Thysanometrinae.

*c*1. Cirrus segments 24-28; cirri very slender with the fourth and following segments greatly elongated, four to five or more times as long as broad; terminal claw straight, tapering to a sharp point; a large black spot on either side of each syzygial pair.

Coccometra guttata.

*c*2. Not more than 25 cirrus segments of which the distalmost are much shorter than the elongate proximal, the penultimate being about as long as broad and at least two of these preceding being much less than twice as long as broad; terminal claw curved.

*d*1. Segments in the distal half of P_1 very short, like those in the proximal half; no black markings; ossicles of the division series and lower brachials with smooth edges; cirri with the antepenultimate and preceding segments markedly longer than broad.

Coccometra hagenii.

*d*2. Segments in the distal half of P_1 becoming elongated, twice as long as broad, with very spinous distal ends; division series and proximal portion of the arms with a prominent black median line; remainder of arms with a large median black

spot on each syzygial pair; ossicles of the division series and brachials with prominently everted and very spinous borders; cirri with the antepenultimate and several of the preceding segments very slightly, if at all, longer than broad.

Coccometra nigrolineata.

*a*2. Cirrus sockets arranged in definite columns, two or three columns to each radial area, on a conical or columnar centrodorsal which is usually as high as, or higher than, broad at the base.

Zenometrinae.

*b*1. Centrodorsal columnar, much higher than broad at the base, with 10 columns of cirrus sockets of which the radial pairs are separated from each other by high ridges; size large; cirri with 40-60 segments.

Zenometra columnaris.

*b*2. Centrodorsal sharply conical, the 10 or 15 columns of cirrus sockets not distinctly segregated into radial groups; cirri with less than 40 segments; P_1 longer than P_2, though never so much as twice as long.

Caryometra.

*c*1. Cirrus sockets arranged in 15 columns on the centrodorsal, 3 in each radial area.

*d*1. Element of the division series and brachials without prominently everted and spinous distal ends, smooth or at most very finely serrate.

*e*1. Cirri at least XXX, not tapering distally, the outer segments not elongated, shorter than the proximal; opposing spine present; terminal claw long and curved.

*f*1. Cirri LX, 17-28, the outermost cirrus segments about half again as long as broad.

Caryometra lisa.

*f*2. Cirri XXX, 30-35, the outermost cirrus segments about as long as broad.

Caryometra tenuipes.

*e*2. Cirri XX-XXV, tapering to a fine point distally, the outermost segments greatly elongated; no opposing spine; terminal claw minute, conical.

Caryometra atlantidis.

*d*2. Elements of the division series and lower brachials with prominently everted and spinous distal ends.

*e*1. Cirri LXV, 24-34, with the outermost 5 or 6 segments about as long as broad; IBr_1 narrow with distally converging lateral borders beyond which the lateral angles of the axillaries extend for a considerable distance.

Caryometra alope.

*e*2. Cirri XXX, 27-34, the distal segments longer than broad; IBr_1 broad with parallel lateral borders which are not overhung by the lateral angles of the axillaries.

Caryometra spinosa.

*c*2. Cirrus sockets arranged in 10 columns on the centrodorsal, 2 in each radial area; cirri with 19-24 segments.

*d*1. Cirri very slender, only slightly curved distally, tapering to a fine point, the distal segments greatly elongated; no opposing spine; terminal claw conical, minute.

Caryometra atlantidis.

*d*2. Cirri less slender, strongly recurved in the distal half, not tapering distally, the distal segments about as long as broad; a long conical opposing spine; terminal claw longer than the penultimate segment, curved.

Caryometra monilicirra.

Subfamily ANTEDONINAE

Antedon dübenii Böhlsche

Antedon dübenii Böhlsche, Archiv f. Naturgesch., 1866, vol. 1, p. 92, figure. P. H. Carpenter (in part), *Challenger* Reports, Zoology, vol. 26, 1888, pl. 37, fig. 2. A. H. Clark, Beiträge zur Kenntnis d. Meeresfauna Westafrikas, Echinoderma II, Crinoidea, 1914, pp. 315, 316.

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Compsometra nuttingi A. H. Clark

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Locality. — *Atlantis* station 3,412;
1 specimen.

Notes. — In this specimen, the second to be reported, the arms are about 30 mm. long. P_1 is 5 mm. long with 23 segments. P_2 is 3.5 mm. long with 9 segments; there is a long fusiform gonad on the third-sixth segments. The cirri are about XXXV.

The perisome of the pinnules contains short, straight, slightly curved or sinuous thorny spicules. The tentacles contain a broad band of similar though much smaller interlaced spicules.

Hybometra senta A. H. Clark

Hybometra senta A. H. Clark, Smithsonian Miscell. Coll., vol. 61, No. 15, December 31, 1913, p. 54.

Subfamily THYSANOMETRINAE

Coccometra hagenii (Pourtalès)

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Coccometra guttata A. H. Clark

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Subfamily ZENOMETRINAE

Zenometra columnaris (P. H. Carpenter)

Antedon columnaris P. H. Carpenter, Bull. Mus. Comp. Zool., vol. 9, No. 4, 1881, p. 169, pl. 1, fig. 8.
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Zenometra pyramidalis A. H. Clark, Proc. U. S. Nat. Mus., vol. 34, 1908, p. 237.

Caryometra monilicirra sp. nov.

(Plate 21, fig. 1)

Description. — The centrodorsal is rounded conical with slightly convex sides, 1.2 mm. broad at the base and about the same from the

apex to the rim. The cirrus sockets are arranged in 10 closely crowded columns of 2-4 (usually 3) each; the pairs of columns in each radial area are not separated from those in adjoining radial areas. The apical portion of the centrodorsal bears a number of cylindrical papillae apparently occupying obsolete cirrus sockets.

The cirri are about XXX, 19-24 (usually 20), the longest 9 mm. long. They are all strongly incurved in the distal half. The first segment is about twice as broad as long, the second is not quite so long as the width of the expanded distal end, the third is somewhat over three times as long as the median width, or twice as long as the width of the expanded distal end, and the fourth, or fourth and fifth, are between five and six times as long as the median width. Those following decrease rather rapidly in length, the last ten or twelve being about as long as broad. The earlier segments have the proximal end slightly expanded and the distal end much expanded and flaring, somewhat more so on the dorsal than on the ventral side, the free edge overlapping the base of the following segment being finely serrate. The short outer segments are half again as broad distally as proximally. The ventral profile is gently and almost regularly concave; the dorsal profile is straight in the proximal half or third, then strongly convex, so that the dorsal distal end is about one-third the width of the base of the segment succeeding below it. The dorsal extension of the distal ends of the outer segments is rounded and not carinate, and is finely spinous with often a somewhat enlarged central spine. On the outer segments the entire distal edge is produced and overlapping with a glassy border, though this is much less conspicuous in the lateral and ventral portions than dorsally. The opposing spine is long, slender, conical, and erect, terminally situated, reaching a height about equal to the distal width of the penultimate segment and arising from nearly the entire dorsal surface of the segment. The terminal claw is somewhat longer than the penultimate segment and is rather slender and moderately curved. The curious knobby appearance of the cirri in their outer portion is very characteristic. The surface of the cirrus segments is marked with very numerous fine punctations.

The distal border of the radials is just visible beyond the rim of the centrodorsal from which their outer surface extends outward at right angles to the dorsoventral axis. In the interradial angles the radials are produced anteriorly, separating the bases of the IBr_1; the anterolateral angles of the radials are separated by a slight notch. The IBr_1 are short, over six times as broad as long in the midradial line, slightly longer laterally than in the midline. They are entirely separated laterally, but their lateral borders are parallel. The dorsal surface is concave. The proximal border is prominent, but smooth. The distal border is slightly produced and finely spinous. The IBr_2 (axillaries) are rhombic, short and broad, half again as broad as long, with the distal edges strongly and the proximal borders less strongly concave. The distal borders are everted and spinous,

this spinous eversion having a somewhat stronger curve than the distal edge; the outer portion of the proximal borders bear a few minute spines. The sharp lateral angles of the axillaries are in contact laterally, forming an irregular water pore beneath them.

The 10 arms are 30 mm. long. The first brachials are about three times as long exteriorly as interiorly. From their inner ends the proximal and distal borders run almost parallel to the midline, then diverge rapidly to the outer border. The proximal border is slightly everted, but unmodified. The distal border is everted and armed with a frill of webbed spines. The inner ends of two adjacent first brachials diverge at an angle of 90°. The second brachials are much larger than the first, irregularly quadrate. The distal border is everted and strongly spinous, and there are some smaller spines on the inner and outer ends of the proximal border. The first syzygial pair (composed of brachials 3 + 4) is slightly longer than broad, oblong or very slightly longer interiorly than exteriorly; the distal border is everted and strongly spinous, and there is a line of lower spines just below the syzygial line. The next four brachials are slightly broader than long, roughly oblong, with the central portion of the distal edge everted and strongly spinous. The brachials following the second syzygy are very obliquely wedge-shaped, longer than broad, with the central portion of the distal edge bearing a frill of spines which gradually diminishes in width and height and disappears at about the middle of the arm, though it may be represented in the outer portion of the arm by a few small glassy spines on the distal edge of the brachials. The brachials following the third syzygy are obliquely wedge-shaped, longer than broad, gradually becoming elongated distally.

Syzygies occur between brachials 3 + 4, 9 + 10, and 10 + 15, and distally at intervals of 2 muscular articulations.

P_1 is 4 mm. long, slender and gradually tapering, becoming filiform distally. It is composed of 13 segments of which the first is short, the second is about as long as broad, the third is half again as long as broad, the fourth is twice as long as broad, and the fifth is nearly four times as long as broad. The segments following rapidly become longer, and exceedingly longated and slender distally. The second and third segments have a prominent tuft of spines on the side toward the arm tip, and those following have flaring and spinous distal ends. P_2 is 3 mm. long with 12 segments of which the first is broader than long, the second is about as long as broad, the third is half again as long as broad, and those following rapidly become elogated, the distal being excessively long and slender. The second, third, and fourth segments have a coarse spine on the distal dorsal end, and those following have overlapping and spinous distal ends. The pinnule is somewhat stouter basally than P_1, but tapers more rapidly in the basal third. The pinnules immediately following appear to resemble P_2.

The spicules in the perisome of the pinnules are long, about two-thirds as long as a pinnule segment, and slightly bent in the middle. The proximal half, lying parallel to the pinnule segment, is usually slightly swollen. The lower end is pointed. The upper end carried several sharp spines of various lengths at right angles to the shaft,

FIG. 1

Caryometra monilicirra; spicules from a distal pinnule. From the holotype, Atlantis station 3435.

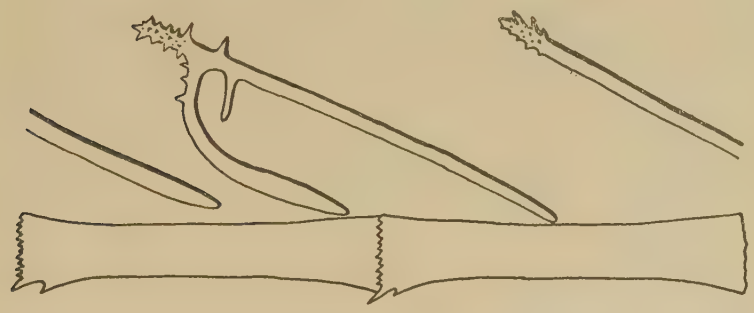


FIG. 2

Caryometra monilicirra; spicules from a distal pinnule. From the holotype, Atlantis station 3435.

of which the most proximal are the longest. Occasionally the first or second spine on the lower side is enlarged and greatly elongated, nearly half the length of the entire spicule, and recurved so that its distal end, which lies along the pinnule segment, is parallel to the main shaft. Very rarely the distal end of the spicule is bifurcated, the bifurcation having short branches.

The color (dry) is yellowish white, the perisome brown.

Locality. — *Atlantis* station 3.435;

1 specimen, the holotype.

Caryometra atlantidis sp. nov.

(PLATE 21, FIGS. 2-4)

?*Antedon liarthra* HARTLAUB, Mem. Mus. Comp. Zool., vol. 27, No. 4, April 1912, p. 399, pl. 7, figs. 8-10; pl. 15, fig. 1.

Description. — The centrodorsal is low conical, broader at the base than high, with the apex rather sharply rounded. The apical third is free of cirrus sockets and finely rougened. The cirrus sockets are arranged in two columns of two each in each radial area. The two columns in each radial area are somewhat closer together than the columns of adjacent radial areas. The upper cirrus sockets are oval, the lower egg-shaped with the more pointed end downward. They are rather deep with a rather high and broad raised rim, and the central portion of the median cavity is abruptly raised into a transversely oval elevation. The sockets in each column alternate with those in the columns adjacent.

The cirri are XX, 22, 25 mm. long. They are slender, and in the distal third taper to a fine point. The first segment is more than twice as broad as long, the second is shorter dorsally but longer ventrally, and the third is about twice as long as the median width, centrally constricted. Those following are greatly elongated, about six times as long as the median width; they increase slowly in width toward each end, more toward the distal than the proximal. After the middle of the cirrus the segments become slightly shorter with the dorsal and ventral profiles straight and parallel; on the last four segments the length progressively increases and the segments taper distally so that the last segment ends in a fine point terminated by a minute, conical, glassy terminal claw. The cirri are entirely smooth dorsally.

The ends of the basal rays are visible as broad low rhombic elevations in the interradial angles.

The radials are short, about six times as broad as long, with the distal border straight. Interradially their anterolateral angles are separated by a notch the sides a which make approximately a right angle with each other. The IBr_1 are about four times as broad as the median length, half again as long interradially as in the midradial line. The lateral edges are parallel and are widely separated from those of their neighbors. The proximal, distal, and lateral borders are smooth and unmodified. The IBr_2 (axillaries) are rhombic, half again as broad as long; the lateral angles overhang the anterolateral angles of the IBr_1. The distal angle is sharp and the two distal edges slightly and evenly concave, the lines from the distal apex to the lateral apices making with each other an angle of about 120° or somewhat more.

The 10 arms are probably about 70 mm. long. The first brachials are about three times as broad as the median length half again as

long exteriorly as interiorly, with the distal border slightly and evenly concave. The inner proximal angles are just in contact over the distal angle of the axillary, and the inner sides make with each other an angle of about 70°. The second brachials are nearly twice as large as the first, with the proximal border smoothly and rather strongly convex. The first syzygial pair (composed of brachials 3 + 4) is about half again as long as broad, slightly longer interiorly than exteriorly. The fifth brachial is nearly as long as the preceding syzygial pair, but the sixth, seventh, and eighth are only slightly longer than broad. The second syzygial pair (composed of brachials 9 + 10) is not quite twice as long as broad; the syzygial line is slightly raised. After the second syzygy the brachials become very obliquely wedge-shaped, longer than broad. The ends of the brachials are unmodified.

Syzygies occur between brachials 3 + 4, 9 + 10, and 14 + 15, and distally at intervals of 3 or 4 muscular articulations.

The broadly exposed interbrachial areas of the disk bear numerous small rounded granules in the central portion.

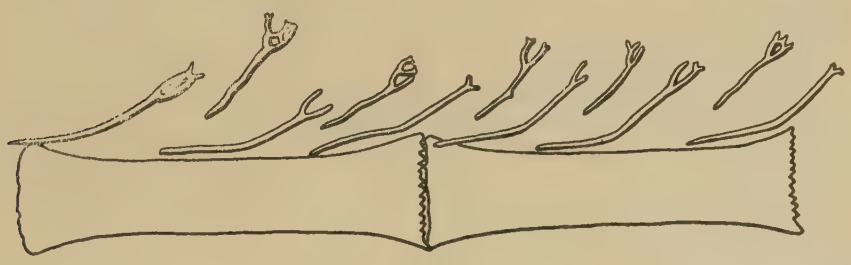


FIG. 3

Caryometra atlantidis; spicules from a distal pinnule. From a specimen from Atlantis station 3412.

P_1 is 5 mm. long, moderately slender, composed of 10 segments of which the first is about as broad as long, the second is twice as long as broad with the distal end slightly enlarged, and the third is three times as long as broad or longer; those following are greatly elongated and slender except the last which is minute, not one-fourth as long as that preceding.

P_2 appears to resemble P_1.

In the perisome of the pinnules there are two rows of spicules, an inner along the pinnule segments and an outer the inner ends of which overlap the outer ends of the spicules of the inner row. The spicules of the inner (lower) row are about half as long as the pinnule segments, slender, and bent or more or less broadly curved in the middle. The lower ends are occasionally bifurcated, the long pointed branches of the bifurcation diverging at an angle of about 90°, and the upper or outer ends are more or less broadened,

sometimes fan-like, and pierced with from one to three holes, more rarely simply or twice bifurcated, the bifurcations with short branches. The outer spicules are about half as long as the inner and correspondingly more slender. The lower end is usually pointed, rarely bifurcated; the upper (outer) end is expanded into a delicate network surrounding usually three large holes; sometimes there are only two holes, or a single hole, and rarely the tip is simply doubly bifurcated.

The color (dry) is yellowish white, the cirri clearer white, the perisome brown.

Localities. — *Atlantis* station 3,391;
4 specimens.

Atlantis station 3,394;
3 specimens, including the holotype described above.

Atlantis station 3,412;
9 specimens.

Notes. — The largest specimen from Station 3,391 has the arms about 90 mm. long. There are three columns of cirrus sockets on the centrodorsal, in each radial area, but one column is represented by only a single socket. P_1 is 6 mm. long with 10-12 segments. P_2 is 5 mm. long, about as stout basally as P_1, smooth and tapering evenly to a delicate tip, with 12 segments of which the first is oblong, half again as broad as long, the second is half again as long as broad, the third is twice as long as broad, and those following gradually become elongated and about six times as long as broad distally. The distal pinnules are long and slender, 11 mm. long with 22 segments.

In the specimens from Stations 3,391 and 3,412, which are preserved in alcohol, the perisome is very light, grayish or dirty yellowish white, and translucent. The interbrachial areas are naked or more or less thickly beset with small calcareous granules, especially in the central portion. The distal intersyzygial interval is usually 3, though frequently 4, muscular articulations.

Hartlaub's *Antedon liarthra* undoubtedly belongs to the genus *Caryometra,* but the specimen from which it was described was so very badly broken as to render its recognition a matter of considerable uncertainty. The columnar arrangement of the cirrus sockets on the centrodorsal is not shown on the drawing (pl. 7, fig. 8) but is evident in the photograph (pl. 15, fig. 1). Hartlaub gives the cirri as about

XXXV, and the best preserved P_1 as 10 mm. long with 13 segments; the total length was estimated as about 12-13 mm.

From the description and figures there is seen to be a fairly close agreement between *Antedon liarthra* and *Caryometra atlantidis*, but the former is larger with the centrodorsal 4.3 mm. in diameter, with more numerous cirri, and with a longer P_1 which is composed of more numerous segments. It is probable that *Antedon liarthra* is the same as *Caryometra atlantidis,* but this is not demonstrable on the evidence at present available. *Antedon liarthra* was dredged by the *Blake* at station 262, off Grenada, in 92 fathoms; the bottom temperature was 62° F.

Caryometra tenuipes (A. H. Clark)

Adelometra tenuipes A. H. Clark, Proc. U. S. Nat. Mus., vol. 34, p. 236, May 14, 1908.

Antedon arcana Hartlaub, Mem. Mus. Comp. Zool., vol. 27, No. 4, April 1912, p. 402, pl. 9, figs. 1, 2, 5, 6, 7-9; pl. 15, fig. 5.

Coccometra arcana A. H. Clark, The Danish Ingolf-Expedition, vol. 4, No. 5, Crinoidea, 1923, p. 41.

Psathyrometra acuta A. H. Clark, Smithsonian Miscell. Coll., vol. 91, No. 4, February 7, 1934, p. 1, pl. 1, figs. 1, 2.

Caryometra tenuipes A. H. Clark, Proc. U. S. Nat. Mus., vol. 83, No. 2,982, March 14, 1936, p. 247.

Note. — The spicules in the perisome of the tentacles are short, slender, usually straight rods with unmodified ends, or occasionally with the distal end bifurcated. They are approximately one quarter the length of a pinnule segment or less.

Caryometra spinosa sp. nov.

(Plate 21, fig. 5)

Description. — The centrodorsal is rounded conical, 2.3 mm. wide at the base and 2.5 mm. higt. The cirrus sockets are arranged in three columns in each radial area, the columns being separated by ridges which are the appressed lateral portions of the elevated rims of the cirrus sockets. The interradial ridges are not distinguishable from the two radial, so that there are 15 equally spaced columns of cirrus sockets about the centrodorsal. The cirrus sockets are laterally flattened, rather deeply excavated with high rims, and have a central transversely oval elevation pierced by the transversely oval central canal. There are two functional cirrus sockets in each column. The obsolete cirrus sockets in the distal half of the centrodorsal are filled

with dense tufts of long fine spicules which give it the appearance of being covered with rather long glassy hairs indistinctly segregated into tufts.

The cirri are XXX, 27-34, from 30 to 33 mm. long, slender and delicate, straight proximally and slightly curved in the distal portion. The first segment is between two and three times as broad as long, the second is about twice as broad as the median length, about twice as long ventrally as dorsally with a strongly concave distal border, and the third is from two to three times as long as its median width with a slightly expanded proximal and much expanded distal end. The succeding segments rapidly become elongated, the sixth and following being six times as long as the median width or even longer, gradually increasing in width in the distal half so that the produced distal edge overlaps the base of the segment succeeding. On the third and following segments the median dorsal portion of the distal edge is produced into a point which slowly increases in length and prominence, becoming a distally directed dorsal spine. The distal overlapping ends of the segments have a narrow glassy border that is widest in the dorsal half where it runs to the dorsal spine. In the distal third of the cirri the segments gradually decrease in length so that the ninth from the end of the cirrus is about twice as long a broad, and the penultimate is only slightly longer than broad. The opposing spine is conical, glassy, arising from most of the dorsal surface of the penultimate segment with its apex in the same line as the distal border of that segment. The terminal claw is somewhat longer than the penultimate segment and is moderately and evenly curved.

The radials are visible as narrow strongly curved bands above the rim of the centrodorsal. Each radial is separated from those on either side by a V-shaped notch. The IBr_1 are short, about six times as broad as long in the median line, with the lateral borders about twice as long as broad, with the anterior angle produced and acute and the anterior sides strongly concave. The distal edges of the IBr_1 and IBr_2 and the lateral portions of the proximal edge of the IBr_2 are strongly everted and coarsely and irregularly serrate. The IBr series are well rounded dorsally and are not in lateral contact.

There are 10 arms. The first brachials are four or five times as long exteriorly as interiorly. The portion from the inner end to the median line is narrow with parallel sides; from the median line to the outer border the proximal and distal edges diverge rapidly. The distal edge is strongly everted and serrate. The second brachials are much larger than the first, irregularly quadrate with a strong rounded proximal process deeply incising the first brachial. The distal edge is strongly everted and serrate. The first syzygial pair (composed of brachials 3 + 4) is slightly broader than long; the distal border is armed with a row of conspicuous and rather long and broad more or less webbed spines. The next five or six brachials

have the distal edge very strongly spinous, but on those following the distal edge is smooth and not produced.

Syzygies occur between brachials 3 + 4, 10 + 11, and 3 + 4, 9 + 10, 13 + 14, and 16 + 17 in the two preserved beyond the base.

P_1 is about 8 mm. long slender and becoming very delicate and filiform distally, with 21 + segments. The first five segments are roughly about as long as broad with broadly rounded angles and small tufts of spines on the middle of the distal side. The following segments rapidly become elongated, those in the distal third of the pinnule being five or six times as long as broad with expanded and overlapping distal ends. P is similar to P_1. P_2 and the following pinnules are much stouter than P_1 — about twice as broad in the proximal portion — but only the bases are preserved. The earlier segments bear a conspicuous broad spine or tuft of spines at the distal end on the side toward the arm tip.

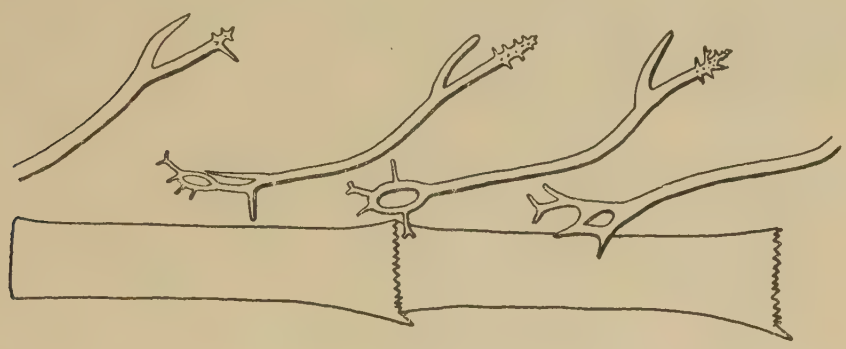


FIG. 4

Caryiometra spinosa; spicules from a distal ponnule.
From the holotype, Atlantis station 3390.

The spicules in the perisome of the pinnules are conspicuous and very characteristic. There is only a single row. The spicules are long, about two-thirds as long as the pinnule segments, rather slender, and abruptly bent or curved upward at a slight angle at about the middle. In some cases the upper branch of the bifurcation bears two long spines on the outer side and ends in a shortly bifurcated tip while the lower branch, which is about half as long as the upper, bears a single spine about half as long as the spines on the upper branch and ends in a bifurcated tip; the upper branch of the bifurcation is nearly one quarter the lenght of the spicule. In other cases the upper branch of the bifurcation bears two processes each with a bifurcated tip and itself ends in a bifurcated tip, while the lower bears one branch with a bifurcated tip, or is without a lateral

branch. This proximal fiburcation of the spicule with the upper branch more developed than the lower is, so far as I am aware, unique. The distal ends of the spicule bifurcate, the branches of the fork being from one-third to one-half as long as the distance from the bifurcation to the central angle of the spicule. The upper branch of the fork is smooth and ends in a sharp point; the lower branch, which is slightly longer, bears in its outer half many slender spines projecting from it at right angles. In the proximal portion of the pinnule the upper branch of the bifurcation usually bears spines on the upper half and the lower branch bears a long downward pointing sharp spine at about the middle, or is itself bifurcated. At the pinnule tips the spicules become reduced to long slender rods curved slightly in the middle with the lower end bifurcated, the branches of the bifurcation being very short, and the upper end undivided and sharply pointed and bearing a few small lateral spines. There are occasional, though rare, modifications. At the pinnule base the earliest spicules are often simple somewhat curved or sinuous rods pointed at the lower end and somewhat roughened at the distal end. One spicule was found in the shape of a Y with all the branches of equal length.

The color (dry) is yellowish white, the perisome brown.

Localities. — *Atlantis* station 2,990;
1 specimen, the holotype.

Atlantis station 3,320;
1 specimen.

Caryometra lísa sp. nov.

(Plate 21, fig. 6)

Description. — The centrodorsal is concial, 2.2 mm. in width at the base and 2.1 mm. from the apex to the rim. The tip, in side view the outermost fourth, is papillose, the obsolete cirrus sockets being occupied by stout cylindrical papillae with spinous or roughened tips. The cirrus sockets are arranged in 15 crowded but regular columns of 3 or 4 each; the outer columns of the radial areas are less closely crowded against those of adjacent radial areas than they are against the central column.

The cirri are about LX, 17-28 (usually 20-25), from 15 to 30 mm. long. The first segment is short, the second is nearly or quite as long as broad, the third is twice as broad as the median width or longer, and the fourth-sixth or seventh are about five times as long as broad. Those following slowly decrease in length so that the terminal are about half again as long as broad. The longer proximal cirrus segments have the distal end slightly enlarged and slightly overlapping. As the segments decrease in length this feature becomes

somewhat more pronounced on the dorsal side forming a narrowly rounded production of the distal dorsal edge that appears as a slight spine in lateral view. The opposing spine is small and poorly developed, terminal in position. The terminal claw is about as long as the penultimate segment, moderately slender and moderately and evenly curved.

The distal edge of the radials is even with the rim of the centrodorsal in the radial line but interradially is much produced anteriorly, so that the anterolateral angles of the radials separate slightly the bases of the IBr_1. The IBr_1 are short, about six times as broad as the median length and twice as long laterally as in the median line; the dorsal surface is slightly concave and the proximal and distal edges are narrowly prominent, but unmodified. The lateral borders curve inward so that the IBr_1 are narrower distally than proximally. The lateral borders are separated from those of the adjacent IBr_1 by an angle of about 45°. The IBr_1 are turned outward so that the mid-dorsal line lies at an angle of about 90° with the dorsoventral axis of the animal. The IBr_2 (axillaries) are rhombic, slightly broader than long, with the anterior and lateral angles acute and the anterior sides strongly concave. A strong rounded proximal process incises the IBr_1. The lateral angles extend beyond the anterolateral angles of the IBr_1.

The 10 arms are about 45 mm. long. The first brachials are short, about three times as long externally as internally. The proximal and distal edges are parallel from the inner side to the middle line, then diverge rather strongly to the outer side. The inner sides lie at right angles to the midradial line, the inner sides of two adjacent first brachials lying in the same plane. The second brachials are much larger than the first and are irregularly quadrate. Their inner angles are in contact over the procumbent inner sides of the first brachials forming a large triangular water pore. The first syzygial pair (composed of brachials 3 + 4) is slightly broader than long and slightly longer interiorly than exteriorly; the sides are slightly concave and the distal border is somewhat thickened and finely spinous. The next four brachials are about half again as broad as long with a concave dorsal surface and sides and the distal edge everted and finely spinous. The second syzygial pair (composed of brachials 9 + 10) is about as broad as the median length and half again as long outwardly as inwardly; the distal edge is everted and finely spinous. The brachials following are obliquely wedge-shaped, about as long as broad, soon becoming longer than broad and distally elongated and less obliquely wedge-shaped. The distal ends of the brachials are moderately spinous, this feature continuing to the arm tips.

Syzygies occur between brachials 3 + 4, 9 + 19, and 14 + 15 (sometimes 13 + 14), and distally at intervals of 2 muscular articulations.

P_1 is 8 mm. long, rather slender and flexible throughout, though especially in the basal third. It is composed of 24 segments of which the first is short and those following gradually increase in length becoming about as long as broad on the seventh and twice as long as broad distally. The earlier segments have their corners out away and all the segments are somewhat constricted centrally with the distal end armed with a row of rather long, stout, sharp spines which are especially prominent on the segments in the distal half. P_2 is about 5 mm. long with 12 + segments. In the basal half it is about as stout as P_1 and the segments are similar though somewhat longer; beyond the seventh the segments become very slender and much elongated. All the segments have spinous ends, and the fifth-seventh bear a gonad.

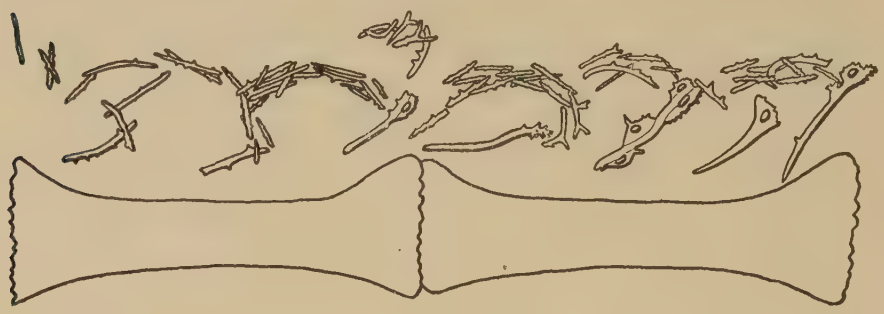


FIG. 5

Caryiometra lisa; spicules from a distal pinnule.
From a specimen from Atlantis station 3407.

Spicules in the perisome of the pinnules are comparatively abundant but small. They are slightly thorny and occasionally forked an the tip. A few are widened and perforated at one end.

The color (dried) is yellowish white, the cirri white.

Locality. — *Atlantis* station 2,990;
1 specimen, the holotype.

Caryometra alope sp. nov.

(PLATE 21, FIG. 7)

Description. — The centrodorsal is conical, 2 mm. broad at the base and 2.5 mm. from the apex to the midradial edge. The cirrus sockets are arranged in three closely crowded columns in each radial area, each column having 4 or sometimes 5 sockets. The tip of the centrodorsal beyond the functional cirrus sockets is finely spinulose.

The cirri are about LXV, 24-34 (the longer usually about 30), from 10 to 23 mm. long, slender and slightly curved distally. The first segment is twice as broad as long, the second is half again as broad as long, the third is about two and one-half times as long as its median width, and the fourth-sixth are nearly four times as long as the median width. The segments following slowly decrease in length so that the outermost five or six are about as long as broad. The third and following segments increase slowly in width distally, and the somewhat produced distal edge overlaps slightly the base of the segments succeeding. The longer earlier segments have the proximal end slightly enlarged. On the third and following segments the central dorsal portion of the distal edge is produced outwardly and distally. Distally this production gradually narrows at the same time involving more and more of the dorsal surface of the segment. On the outermost segments of the longest cirri it becomes a high, more or less narrow, subcarinate or even sometimes carinate, elevation with a convex crest the dorsal end of which rises for some distance above and overlaps the base of the segments succeeding. The opposing spine is long, conical, sharp, and glassy, about as long as the distal end of the penultimate segment, from almost the entire dorsal surface of which it arises. The terminal claw is longer than the penultimate segment, rather slender and moderately curved.

The radials in the mid-radial line are just visible beyond the rim of the centrodorsal. The distal border is very strongly concave, the lateral portions being extended far upward separating the bases of the IBr_1. The IBr_1 are very narrow and band-like, curved strongly upward laterally, five or six times as broad as the median length. The distal border is produced and armed with rather long fine webbed spines. The IBr_2 (axillaries) are rhombic, broader than long, with all the sides, especially the two anterior, concave, the anterior angle narrow and much produced, and the lateral angles also narrow and produced, considerably overhanging the anterolateral angles of the IBr_1. The distal borders are everted and armed with evenly spaced rather long broadly webbed spines.

The 10 arms are about 60 mm. long. The first brachials are between four and five times as broad as the median width. The inner half tapers from the median line almost to a point, and the proximal and distal edges of the outer half diverge so that the outer side is about twice as long as the length in the median line. The proximal border is slightly everted and smooth, and the distal border is strongly everted and armed with a row of webbed spines. The second brachial is irregularly quadrate, about half again as broad as long. Their inner borders curve inward over the inner ends of the first brachials forming a conspicuous water pore. The distal border is strongly everted and armed with webbed spines. The first syzygial pair (composed of brachials $3 + 4$) is not quite twice as broad as long, and is half again as long interiorly as exteriorly. The hypozygal is wedge-shaped, about three times as long interiorly as exteriorly. The inner and

outer sides of the epizygal are of about the same length, and the distal edge is rather strongly concave, strongly everted, and armed with webbed spines. The next four brachials are twice as broad as long, almost oblong with somewhat concave lateral borders and the central portion of the distal edge raised into a high erect frill of webbed spines. The brachials following the second syzygy are very obliquely wedge-shaped, longer than broad, with the central portion of the distal edge armed with a high frill of webbed spines that disappears after about the twenty-fifth brachial. Distally the brachials become longer with slightly concave sides and smooth ends.

Syzygies occur between brachials 3 + 4, 9 + 10, and 14 + 15, and distally at intervals of 2 muscular articulations.

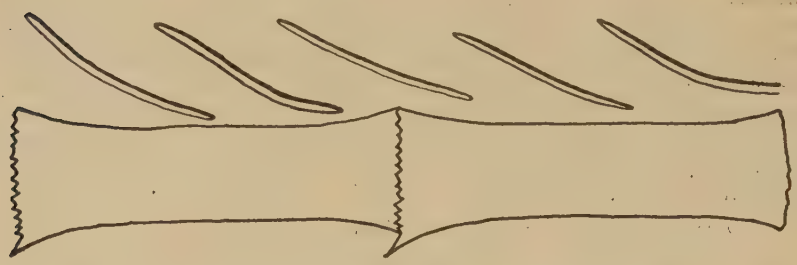


FIG. 6

Caryometra alope; spicules from a distal pinnule. From the holotype, Atlantis station 2989.

P_1 is about 6.8 mm. long, slender, very flexible basally, becoming filiform and less flexible distally. It is composed of about 24 segments of which the first five or six are about as long as broad with the corners cut away, the eighth or ninth is twice as long as the median width with the distal end strongly flaring and overlapping and the proximal end somewhat enlarged, and those following slowly increase in length, the distal being very slender and five or six times as long as broad or even longer. The elongated segments have expanded distal ends that overlap slightly the somewhat enlarged bases of the segments succeeding. The short proximal segments have tufts of webbed spines on the convex side toward the arm tip. P_2 is about 5.7 mm. long with about 13 segments of which the first is broader than long, the second and third are about as broad as long, and those following gradually increase in length, becoming much elongated distally. The pinnule is about as stout basally as P_1, but it tapers more slowly and consequently appears considerably stouter in its basal half. The distal ends of the segments are more or less produced, and some of the proximal segments bear fine spines on the distal ventral border and a single large spine on the distal end

of the side toward the arm tip. The slender distal segments have swollen ends, the distal ends being overlapping and finely spinous. The fourth-eighth segments bear a gonad. The distal pinnules are 9 mm. long with about 20 segments of which the first two are short and broad and those following rapidly become elongated and very long and slender distally. The distal ends of the segments are overlapping and very finely spinous.

Spicules in the perisome of the pinnules appear to be very scarce. They consist of very slender straight or slightly curved rods with unmodified ends.

The color (dry) is yellowish white, the cirri white.

Locality. — *Atlantis* station 2,989;

1 specimen, the holotype.

Subfamily PEROMETRINAE

Hypalometra defecta (P. H. Carpenter)

Antedon defecta P. H. Carpenter, *Challenger* Reports, Zoology, vol. 26, 1888, pp. 54, 206.

Hypalometra defecta A. H. Clark, Proc. Biol. Soc. Washington, vol. 21, 1908, p. 133.

Subfamily BATHYMETRINAE

Trichometra cubensis (Pourtalès)

Antedon cubensis Pourtalès, Bull Mus. Comp. Zool., vol. 1, No. 11, 1869, p. 356.

Antedon aspera A. H. Clark, Proc. Biol. Soc. Washington, vol. 21, 1908, p. 131.

Trichometra aspera A. H. Clark, Proc. Biol. Soc. Washington, vol. 21, 1908, p. 132. A. H. Clark, Proc. U. S. Nat. Mus., vol. 34, 1908, p. 229.

Trichometra cubensis A. H. Clark, The Unstalked Crinoids of the *Siboga* Exped., March 1918, p. 247.

Trichometra minutissima (A. H. Clark)

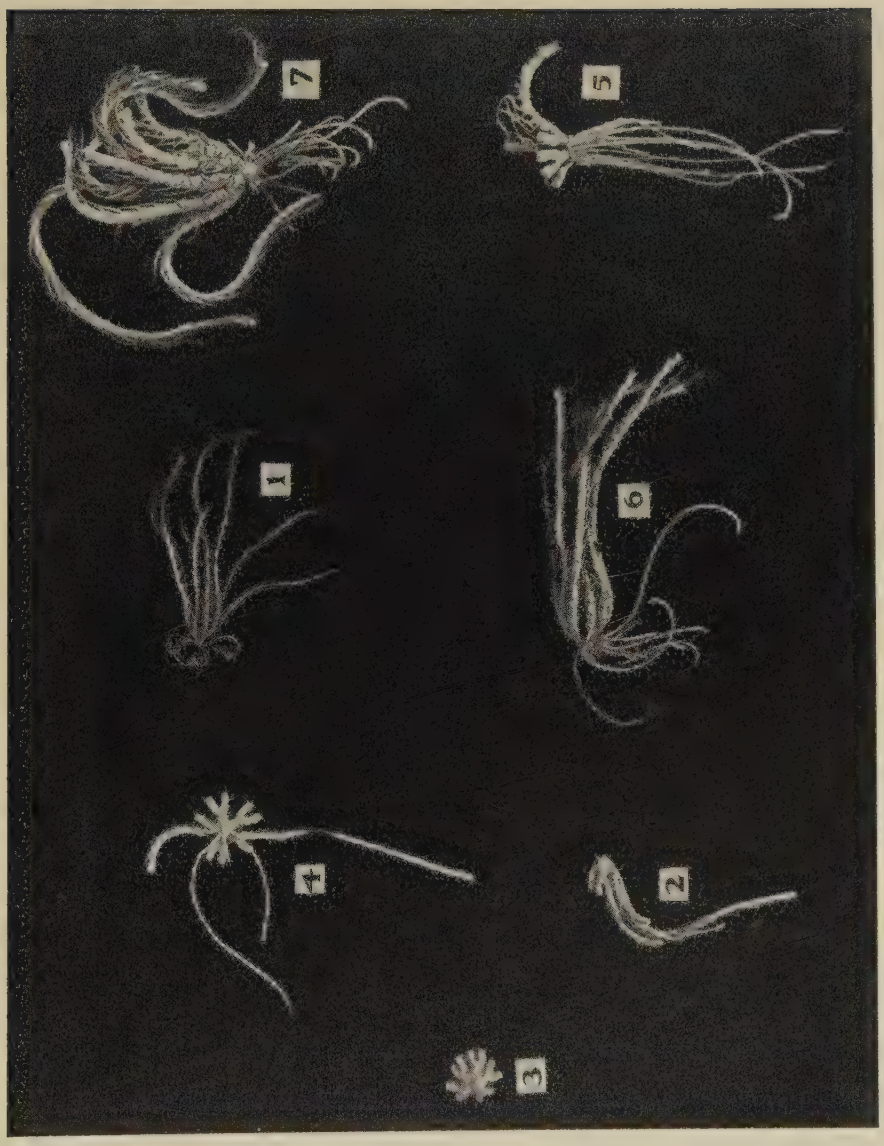
Bathymetra minutissima A. H. Clark, Proc. U. S. Nat. Mus., vol. 34, 1908, p. 233.

Trichometra minutissima A. H. Clark, The Unstalked Crinoids of the *Siboga* Exped., March 1918, pp. 247, 248.

EXPLANATION OF PLATE 21

ALL FIGURES ARE × 2

FIG. 1.	– *Caryometra monilicirra.*	Type.	Station	3,435.
„ 2.	– *Caryometra atlantidis.*		„	3,394.
„ 3.	– *Caryometra atlantidis.*	„	„	„
„ 4.	– *Caryometra atlantidis.*	„	„	„
„ 5.	– *Caryometra spinosa.*	„	„	2,990.
„ 6.	– *Caryometra lisa.*	„	„	„
„ 7.	– *Caryometra alope.*	„	„	2,989.



CLARK: The Family Antedonidae.

Contribution No. 257

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Printed in U. S. A.

EFFECTS OF MARINE MUD UPON THE AEROBIC DECOMPOSITION OF PLANKTON MATERIALS [1]

CHARLES E. RENN

(From the Woods Hole Oceanographic Institution [2] and the Harvard University Graduate School of Engineering [3])

A number of recent investigations of bacterial activity in natural fresh and salt waters, in soils, and in muds strongly suggest that the rates of bacterial decomposition in these sites may be modified by finely divided and colloidal inorganic materials.

It is noted that marine bacteria are carried from suspension by settling marine and salt lake muds. To an undetermined degree encapsulated clumps, slime masses, and bacterial chains are mechanically occluded in the precipitating material, but the ratio of cells removed bears a relation to the electrical charges borne by the muds and bacteria characteristic of physical adsorption (3, 4, 5). Terrestrial soils also carry down adhering bacteria from suspensions. The degree of concentration may be varied by altering the charge on the soil particles (3).

Many marine and fresh water bacteria are sessile in habit, and it has been observed that the amount of bacterial substance in the attached films that these organisms form greatly exceeds the concentration in the surrounding water (6, 7). When the ratio of surface/volume in stored sea water is increased, the bacterial numbers rise and various physiological processes are stimulated. It has been suggested that the higher biological oxygen consumption associated with the increase in surface may be related to the adsorption and concentration of soluble organic materials and bacterial enzymes upon the enclosing surfaces (8).

Soluble and finely divided organic materials are themselves adsorbed on fresh water muds. River silts carry organic matter from muddy water to the bottom as they settle (2). From comparative studies of the biological oxygen demand characteristics, it appears that the organic matter in the silts breaks down at a much lower rate than that of the water from which they settled.

The experiments reported in this paper are attempts to discover if

[1] The author is indebted to the Elizabeth Thompson Science Fund for a grant of money which made possible the construction of the special respirometer apparatus and supplementary equipment used in this investigation.

[2] Contribution No. 257 from the Woods Hole Oceanographic Institution.

[3] Contribution from the Harvard Graduate School of Engineering No. 277.

marine muds affect the rates at which plankton materials undergo aerobic decomposition in the superficial layers of the sea bottom. Studies on the breakdown of sewage sludges indicate that aerobic conditions may prevail in the upper centimeter of the active mass, and it is probable that this also applies to the more flocculent surface muds receiving freshly settled debris from the sea (1).

Surveys of the distribution of organic matter and bacteria in marine muds indicate that biological changes go on relatively slowly in the sea bottom. It was thought, initially, that the adsorption of organic matter on the materials of the mud might be a significant factor in limiting bacterial activity.

Experiments on the Adsorption of Plankton Materials by Marine Mud

Materials

The mud used in these experiments was prepared from a series of short cores, 4 to 6 inches deep, taken from a station in the Gulf of Maine (N. 42° 25′, W. 70° 35′) at a depth of 100 meters. It had been stored for a year in the laboratory at room temperatures. A week before the work began the material was mixed with "aged" sea water and repeatedly suspended to remove heavy sand, fine gravel, shell particles, and other large fragments. A final suspension was made and aerated gently for three days. This was allowed to set—the heavy fraction separating within thirty seconds was discarded, and the remainder drawn off for use. The gross analysis of this mud was as follows:

Loss of weight on drying at 105° C. (corrected for salt content)	71.0 per cent
Loss of weight on ignition (on dry weight, salt-free basis)	11.5 per cent
Total nitrogen (on dry weight, salt-free basis)	0.20 per cent
Content of nitrogen per ml. wet mud as used in the experiments	0.70 mgm./ml.

Fresh plankton suspensions were prepared for each experiment from tows taken in Vineyard Sound (collected with No. 20 silk net, chilled, and prepared within four hours). This material consisted predominantly of species of *Rhizosolenia*. The tow was ground and filtered by suction through washed No. 52 Whatman filter paper. Nitrogen content of the extract was determined by micro-Kjeldahl, and convenient sea-water dilutions were prepared from the concentrated stock.

Determination of Adsorption

Varying concentrations of mud and plankton extract were stirred together on a gently rocking shaker for different intervals of time. Samples were withdrawn and nitrogen analyses made on aliquots of the mixture. Fifty-milliliter quantities of the mixture were placed in a clinical centrifuge and whirled until clear. Separate nitrogen determinations were made upon the mixture, upon the supernatant, and upon the centrifugate. The adsorption of plankton extract on mud in various

TABLE I

Adsorption of Nitrogenous Materials by Marine Mud

A. Plankton Extract

Concentration of N in extract 0.60 mg./ml.
Concentration of N in mud 0.70 mg./ml.

Ratio of mud to extract	N in supernatant after centrifuging (three-hour mixing)	N adsorbed by mud in three hours	N in supernatant after centrifuging (twelve-hour mixing)	N adsorbed by mud in twelve hours
	mg./ml.	*per cent*	*mg./ml.*	*per cent*
1 : 5	0.36	40	0.34	43
1 : 2.5			0.31	49
1 : 1	0.23	61	0.20	67
2 : 1	0.12	80	0.11	82

B. Peptone Solution

Concentration of N in solution 0.55 mg./ml.
Concentration of N in mud 0.70 mg./ml.

Ratio of mud to solution	N in supernatant after centrifuging (twelve-hour mixing)			N adsorbed by mud in twelve hours
	mg./ml.			*per cent*
1 : 25	0.42			23
1 : 2	0.13			77

mixtures under these conditions is demonstrated in the data given in Table I.

It is evident from this that the nitrogen-bearing fraction of plankton extracts are strongly adsorbed on marine mud. The concentrations involved in these experiments are several thousand times as high as those occurring in sea water but fall within the ranges that occur in marine muds.

Soluble materials such as plankton extract and peptone are readily

adsorbed at room temperatures, but bacterial digests of the same material are not removed to a comparable degree. In an experiment with a dense suspension of mixed bacteria grown in plankton extract, only 10 per cent of the nitrogen was adsorbed from suspension by mud stirred for 12 hours and centrifuged under conditions comparable to those applying in the other experiments. Microscopic examination of the mud thrown down showed the bacteria moving freely through spaces between particles—the centrifugate remained cloudy with motile bacteria.

Experiments on the Effect of Mud on Rates of Aerobic Decomposition

Breakdown of Particulate Plankton

Previous experiments on the rates of decomposition of organic matter in marine muds have been quantitatively unsatisfactory because of the technical limitations of the standard biological oxygen demand method. In these experiments the difficulties were eliminated by using a series of respirometers. The apparatus was designed by the author for the direct measurement of oxygen consumption of such organic matter rich systems as grossly polluted waters, sewage sludges, and manured soils. A description of their design and applications will be published in the near future.

In the first experiment the respirometers were filled with mixtures of mud and finely ground, unfiltered plankton. Duplicate respirometers were used for each mixture and filled as follows:

Set A—4 units mud in 200 ml. aged sea water
Set B—2 units mud, 1 unit plankton in 200 ml. aged sea water
Set C—1 unit mud, 2 units plankton in 200 ml. aged sea water
Set D—4 units plankton in 200 ml. aged sea water

Carbon analyses were not available for the plankton material, but satisfactory approximations may be made from the nitrogen determinations. Assuming a C/N ratio of 10:1 for the organic matter of the mud, the organic carbon value of the unit of mud is about 3.5 mgm. If a C/N ratio of 8:1 is taken for the plankton, the value of the plankton unit in terms of organic carbon is 2.4 mgm.

During the five-day term of this experiment the temperature was 23° C. ± 0.5° C.

The oxygen consumption of the various mixtures is plotted against time in Fig. 1.

Greatest irregularities occur in the duplicate samples of mud—possibly through the accidental inclusion of organic particles. It can be

assumed that the oxygen consumed in this interval was utilized in the biological oxidation of the organic carbon in the plankton material. On this basis a little over 50 per cent of the plankton carbon was oxidized during the five days of activity. The organic matter of the mud is more stable—in the same interval about 7 per cent of this carbon underwent oxidation.

In the mud and plankton mixtures the amounts of organic carbon oxidized to carbon dioxide are not significantly different at any time from the values that would be estimated from the consumptions of the separate

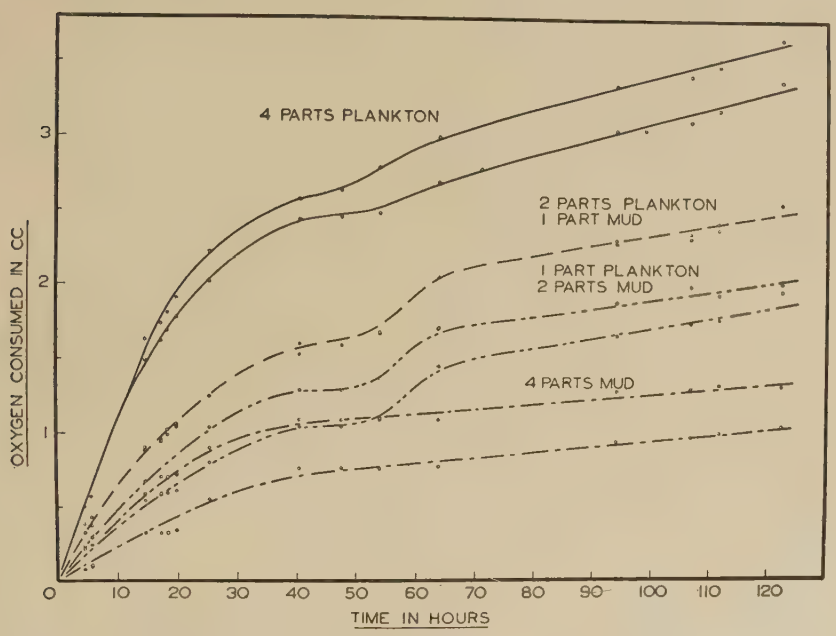

FIG. 1. Biological oxygen consumption in sea water suspensions of mud (lower set of curves), of ground plankton (upper curves), and of mixtures of mud and plankton (intermediate curves).

components. There is a slight increase in the proportion of carbon oxidized in the mixtures, but this effect is most pronounced in the lower concentration of plankton and may be related to the dilution effect observed in the third experiment.

Breakdown of Plankton Extract

A second experiment was prepared, using plankton extract instead of fine, particulate plankton. Mud, plankton-extract, and sea water were placed in sets of duplicate respirometers as follows:

Set A—4 units mud in 200 ml. aged sea water
Set B—2 units mud, 1 unit plankton, 200 ml. sea water
Set C—1 unit mud, 2 units plankton, 200 ml. sea water
Set D—4 units plankton in 200 ml. sea water

The nitrogen values of the mud and plankton units in the charges were adjusted to equal those of the first experiment. During the five days of activity the temperature ranged about 23.5° C. ± 0.5° C.

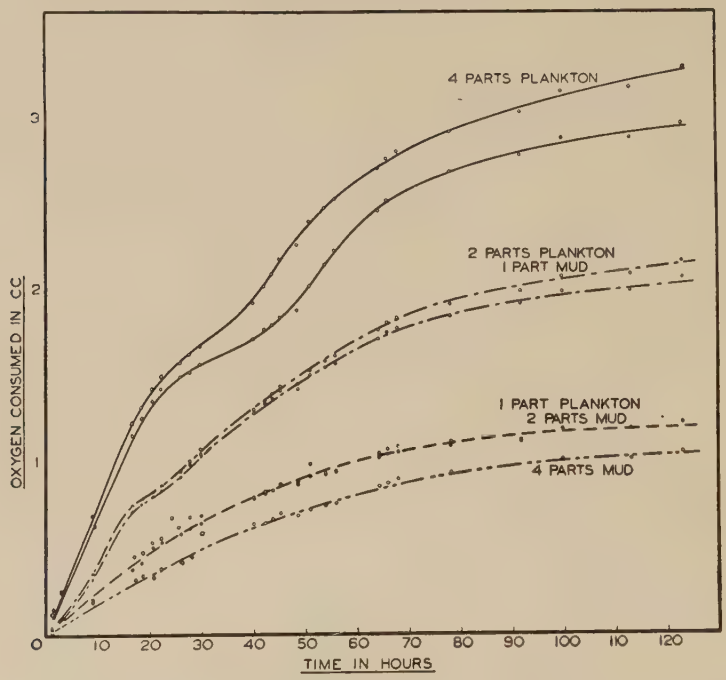

Fig. 2. Biological oxygen consumption of sea water suspensions of mud, plankton extract, and of mixtures of mud and plankton extract.

At the end of the second experiment approximately 45 per cent of the plankton carbon had been oxidized and between 6 and 7 per cent of the organic carbon in the mud. Very slightly more oxygen was consumed in the mixtures than would be calculated, but this difference is not significant when the greater efficiency of breakdown in the more dilute suspensions (Exp. 3) is considered.

Effect of Concentration on Decomposition in Mud

In the final experiment an attempt was made to discover what effect might be expected in rich mixtures of mud and plankton as compared

with the relatively dilute suspensions of mud and plankton used in the first two experiments. The respirometers were loaded in the following manner:

Set A—4 units mud (no added sea water)
Set B—2 units plankton extract, 2 units mud
Set C—2 units plankton extract, 2 units mud, 100 ml. aged sea water
Set D—4 units plankton extract (no added sea water)

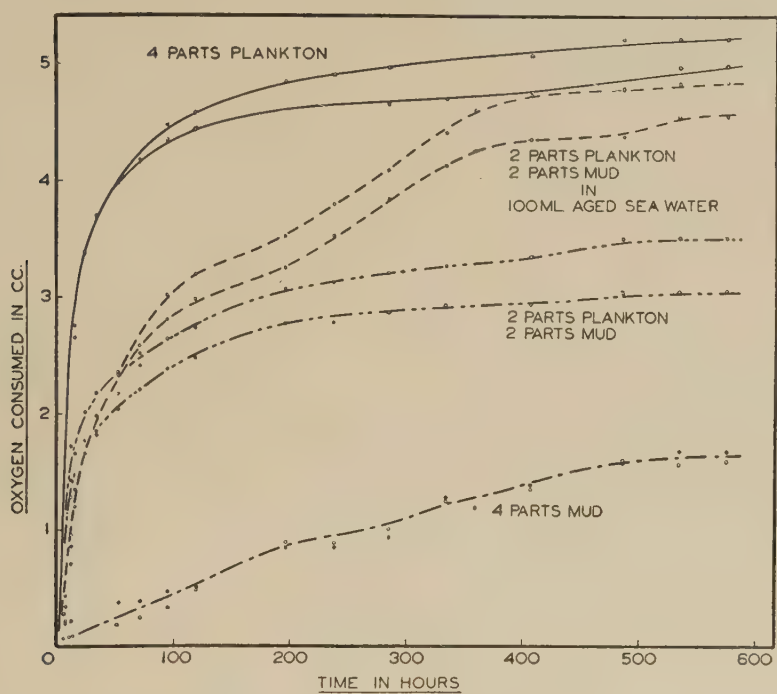

FIG. 3. Biological oxygen consumption concentrated mud, plankton extract, mixtures of plankton extract and mud, and of a sea water suspension of mud and plankton extract.

Although the rate of oxygen uptake had markedly decreased by the end of five days at 23.0° C. ± 0.5° C., the experiment was continued for 24 days.

At the end of this time 75 per cent of the organic carbon in the plankton extract had been oxidized and about 16 per cent of that in the mud. The undiluted mixture of mud and plankton consumed oxygen at a rate practically equal to that anticipated from the rates of consumption in the separate mud and plankton cultures.

The oxygen demand curve of the mud and plankton mixture diluted with 100 ml. of sea water is markedly different, however. It indicates a more rapid consumption of oxygen during the first hundred hours and a prolonged demand during the next three hundred hours. The oxygen consumed at the end of the active period—300 hours—is about 50 per cent greater than that taken up by the concentrated mud and plankton mixture. This effect of dilution is not related to the oxygen consumption of the added, aged sea water. Repeated determinations were made on the water alone and in no case did the oxygen demand of five-day intervals exceed 0.2 ml. per liter.

Discussion

It appears from these experiments that marine muds have little if any direct effect upon the rates at which readily decomposed organic materials that may be mixed with them undergo aerobic decomposition.

The fact that marine muds adsorb nitrogenous organic materials may be significant, however, in determining the normal course of their breakdown. Soluble organic matter released by autolytic or digestive processes may be localized in the mud where anaerobic changes and low temperatures prevail.

It is unlikely that silts perform transport functions in the sea as they do in the slow-flowing parts of silt-laden rivers, but by slowing down the rates of diffusion and maintaining relatively high local concentrations, muds may lower the effective rate of bacterial decomposition in the bottom.

Summary

1. Marine muds strongly adsorb soluble nitrogenous organic materials of plankton origin.

2. Muds exert little if any direct effect upon the rates or efficiency of anaerobic bacterial decomposition of plankton materials.

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Contribution No. 258

THE NECESSITY OF A NEW APPROACH TO THE STUDY OF THE CIRCULATION ON THE CONTINENTAL SHELF

C. O'D. Iselin

(Contribution No. 258 of the Woods Hole Oceanographic Institution)

Wherever the continental shelf is at all wide and provided there is sufficient river-water entering the sea, a current-system develops parallel to the coast due to the relatively low density of the inshore waters. These currents, which are here called coastal currents, have several striking differences from the type of flow found offshore in deep waters. In the first place, in typical areas inside the 100-fathom curve the salinity increases with depth, which is the reverse of the situation found in most deep, oceanic areas. Moreover, the vertical and horizontal gradients of salinity often outweigh the temperature-distribution in determining the pattern of density. In most coastal areas the density-distribution is the cause and not the result of the currents.

As is now well understood, the Circulation Theorem of Bjerknes can be applied to any type of steady current-system, whatever its cause. Thus in analyzing dynamically the flow near the edge of the continental shelf, where the coastal type of current is often parallel and in close contact with an oceanic type of movement, one does not have to take into account that offshore the distribution of density is the result of the movement while inshore it is the cause. However, it is becoming increasingly clear that only in the case of quite strong coastal currents does the ordinary application of the Circulation Theorem give a reasonably correct picture of the current-pattern.

There are several well-known reasons why one should be distrustful of weak current-patterns derived from the dynamic analysis of a network of stations made on a wide continental shelf. Not only are the complications resulting from short-period interval waves often particularly troublesome, but in many areas the velocity of the tidal currents far surpasses that of the gradient-flow, so that the assumption of a steady state of motion is most questionable. In addition, the relatively great difference in depth from station to station introduces a difficulty which cannot be solved in a satisfactory manner. It is perhaps for these reasons that during recent years some physical oceanographers have preferred to study currents in deep water.

Unfortunately for the physicist, who finds that the oceanic currents still provide plenty of food for thought, the marine biologists have their main interests in the shallow seas which are much more productive in the commercial sense. Any fisheries-research program is greatly facilitated by a knowledge of the current-pattern in the area under investigation and at present there is no single reliable method for obtaining this information, unless the currents are strong. The productive fisheries are often located in areas of relatively weak gradient-flow. This is very much the case with Georges Banks, now being intensively investigated by the biologists of the Woods Hole Oceanographic Institution. In this area it seems nearly hopeless by the ordinary water-bottle technique to secure physical observations which will provide information on the currents to supplement the biological surveys. Moreover, as is so often the case in fisheries-investigations, the physical observations must be secured as rapidly as possible and for the most part at points selected by the biologists. Working from a single ship it is nowadays most difficult to combine both physical and biological observations into a survey which is satisfactory from either point of view.

But assuming no conflict with biological requirements, how can one learn about the movements prevailing in such an area as Georges Banks? At the present time we have three well-tested techniques, namely, water-bottle observations, current-meter measurements, and drift-bottle experiments. None of them provides the sort of information which is really most needed.

Because laterally the temperature-salinity correlation changes so rapidly in many coastal areas, it seems clear that the cross-current components are often relatively strong. On a fishing bank, where the gradient-flow usually is peripheral (clockwise around the edge of the bank in the Northern Hemisphere), the cross-current transfer is much more significant biologically than the more obvious flow at right-angles to the pressure-gradient. The cross-current components primarily supply sufficient salt to the waters over the continental shelf to counteract the diluting effects of land-drainage. In many coastal areas this is no insignificant amount. Typically the relatively saline offshore-waters penetrate landwards along the bottom, especially along gullies and drowned river-valleys, while at the surface fresher waters escape offshore. For the New England region, the land-drainage figures and the vertical salinity-gradient over the continental shelf indicate that roughly 15 per cent of the waters of the whole Gulf of Maine

must be renewed each year by inflow from offshore along the bottom. Near the outer edge of the continental shelf the renewal may well be more rapid than close to the shore. It seems likely that the interchange between Georges Banks and the surrounding seas proceeds at an average rate of as much as ten per cent per month. In this case the cross-current components are perhaps mass-movements and not the sort of lateral frictional transfer visualized under the theory of isentropic mixing.

From the biological standpoint it is clearly desirable to learn as much as possible concerning the cross-current components of coastal circulation. From the physical point of view also, these probably constitute the most promising clue to the circulation-problem in coastal areas. It will be of great interest to learn not only the amount of lateral transfer, but also how much of it can be accounted for by frictional forces and how much by actual mass-movements in the direction of the Archimedian force. The latter are of course to be expected, if the flow is not steady in the sense required by the Circulation Theorem.

As mentioned already, coastal circulation is in many areas characterized by strong tidal oscillations. Thus in examining the mixing processes the observer should not remain in the same geograpnical position, but should move with the water-mass being studied. It seems probable that a profitable method of attack might involve the use of a marker-buoy which would allow the research-vessel to follow the changes of the temperature-salinity correlation in a given mass of water near the boundary between the coastal water and the offshore water. This buoy could be anchored by a drag to whatever layer is desired. Its movement across current from day to day would be a measure of the mass lateral transfer, while the repeated water-bottle observations near the buoy might provide data on the coefficients of lateral and vertical turbulence.

It seems possible that in certain cases two or more such buoys, each anchored to different subsurface layers, might provide relatively exact measurements, even though the lateral mass-transfers were quite slow. Easy and accurate repeated measurements can be made of the distance apart and bearing of a pair of floats. Likewise, the movements of these floats anchored to various subsurface layers can be measured relative to a float anchored to the bottom.

This is the sort of information needed by biologists to understand the dispersal of fish eggs and the movements of the plankton. It would, I believe, also greatly assist the physicists in understanding the nature of the current-system in regions where there is reason to doubt the applicability of the ordinary dynamic technique.

Besides the more or less steady interchange between the relatively fresh waters on the continental shelf and the more saline offshore-waters, it seems likely that from time to time, either because of the winds or because of the formation of large frictionally driven eddies, considerable masses of coastal water are carried offshore near the surface. When this takes place the compensation may occur at some quite distant part of the continental shelf. In all probability an equivalent volume of more saline water must move inshore along the bottom. It seems possible that such major disarrangements of the coastal circulation can have important biological consequences, especially during the spawning season. If the causes for such rather sudden breakdowns in the normal pattern of coastal circulation were more clearly understood, it might be possible for fisheries-investigators to predict the future catch without having to sample year after year the new additions to the population. Physical oceanographers have rather avoided inquiring into the causes of ocean-currents. They have been content merely to note that for several reasons they do flow. In the case of coastal currents, however, a better understanding of the factors which from time to time disturb them might open up many new lines of investigation. It is partly for this reason that it is being urged that more effort be made to perfect an observational procedure which has a chance of uncovering causes. The techniques now in general use seem largely to overlook this possibility.

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FLOOR OF THE NORTH PACIFIC OCEAN

F. Betz, Jr., and H. H. Hess

During the last few years, ships of the United States Navy have taken a huge number of sonic soundings on lines crossing the North Pacific Ocean. As a result of these it was possible for the Hydrographic Office to publish a new bathymetric chart of this area last year, which was a great improvement over previously existing bathymetric charts.

Contribution No. 259

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PHYTOPLANKTON AND PLANKTONIC PROTOZOA OF THE OFFSHORE WATERS OF THE GULF OF MAINE

Part I—Numerical Distribution [1]

By Henry B. Bigelow, Lois C. Lillick, and Mary Sears

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Abstract

Except for occasional local flowerings, the phytoplankton is scanty from late autumn until early spring (av. 1,852,000–7,856,000 cells per column). In the one year of record the minimum was reached in December in the western coastal belt and over George's Bank, but not until January in the eastern side generally. In most years, an increase in the phytoplankton takes place by mid- or late March (late February in an early spring) in the western coastal belt, western George's Bank and in Passamoquoddy Bay. In some years, the flowering may start equally early in the eastern side of the Gulf, south from Nova Scotia and over the eastern part of George's Bank, but not until April or even May in the northern coastal belt or over the bowl generally.

[1] Contribution No. 259 from the Woods Hole Oceanographic Institution.

The vernal climax (averaging 2–14 billion cells per column) is reached by early or mid-April in the vicinity of Massachusetts Bay and over the eastern part of the Gulf generally, by late April in the southern part of the western basin, shortly thereafter in the northern coastal belt, and latest (May or June) in the Bay of Fundy region.

Subsequent to the vernal climax, a rich flora may persist in the northern coastal belt, in the Bay of Fundy and (judging from available evidence) also on George's Bank through June or July. Elsewhere an abrupt impoverishment follows the vernal climax—so severe in the open basin as to make the May counts lower than at any other season.

A second flowering takes place through August, the more productive centers being in the Bay of Fundy region and on George's Bank. Similar centers occur in the Massachusetts Bay region and southward in September. This increase is followed by a progressive autumnal impoverishment whereby the winter condition is re-established.

The initiation of the vernal flowerings is apparently not dependent on the available nutrients, on light, or on the attainment of any particular temperature, but is possibly conditioned by a certain amount of stability in the water column. Nutrients, on the other hand, play a part in the termination of the vernal multiplication, nitrates perhaps being more likely to act as the limiting factor than phosphates. Apparently, the nitrate supply is replenished in the illuminated zone before the second flowering.

The planktonic protozoa of the Gulf of Maine, at their lowest level from October on, increase considerably from May through June, reaching a maximum in July.

INTRODUCTION

The general composition of the plankton of the Gulf of Maine, both animal and vegetable,[2] is now well known. Davidson (1934) and Gran and Braarud (1935) have also contributed quantitative studies of the latter for the region of the Bay of Fundy. The collections [3] made on the periodic cruises of "Atlantis" during the year 1933–1934 now provide the basis for a general survey of the numerical distribution of planktonic plant cells for the gulf as a whole, from season to season.

Sources of Information

Quantitative collections at representative localities (Figs. 2, 3, 4) made from "Atlantis" in June, July, September, October and December, 1933, and in January, March, April, May, June and July, 1934 and in August, 1936 form the chief basis of the present report. Information has also been freely drawn from earlier publications, both for the offshore waters of the gulf (Bigelow, 1914–1922, 1926; Gran, 1933; Braarud, 1934; Gran and Braarud, 1935), for the Bay of Fundy, and for various inshore localities (Bailey, 1910–1924; Bailey and Mackay, 1921; McMurrich, 1917; Fritz, 1921; Davidson, 1934; Burkholder, 1933; Gran and Braarud, 1935).

Methods

The first efforts at quantitative determination for the general region were based on horizontal net-hauls (Fritz, 1921; Bigelow, 1926; Davidson, 1934). Lacking information as to the amount of water strained, these not only involved all the errors of the tow-net method *per se*, but could yield only relative information at best. More recent studies, however, have been based on determinations of amounts of plankton contained in known volumes of water. And successive investigators can claim increasingly greater accuracy, for

[2] See especially Bigelow, 1926.

[3] The original data are on file at the Woods Hole Oceanographic Institution. For a preliminary account see Lillick (1938).

whereas Burkholder (1933) filtered the water sample through fine bolting silk, Gran (1933), Braarud (1934) and Gran and Braarud (1935) employed the "centrifuge" method, and the counts of "Atlantis" samples here presented were by Untermoehl's (1931) precipitation method as modified by Steemann Nielsen and Von Brand (1934).

FIG. 1. Chart of the Gulf of Maine showing localities mentioned in the text.

Our standard procedure was to make counts of 20–50 cc. taken from a 1-liter sample of water collected with the Nansen water bottle at depths of 1, 10, 30, 50 and 80 meters, 10% being added to the counts to compensate for the amount lost during the operation as Gran (1933, p. 160) has shown to be necessary. Most, however, of the counts for the

April–May and May–June cruises of 1934 were of aliquot samples (concentrated over a membrane filter) of catches made in vertical tows from 100 meters (or less) with ordinary tow-nets of No. 20 silk, 35 cm. in diameter.

Our aim has been to present a picture of the numbers of plant cells existing in the water column as a whole at different seasons and localities, as one step in current studies of organic production in the Gulf. The numbers of cells are therefore stated per 0.1 square meter of sea surface rather than per liter. In the case of the water-bottle collections, this value is arrived at by the following arithmetic calculation, the assumption being that practically the whole phytoplankton was in the upper 80 meters:

1. $$\frac{\text{Summation of } (\Sigma) \text{ (average number of cells per liter} \times \text{depth in meters of each stratum sampled)}}{\text{Total depth sampled in meters}} = \text{Average number of cells per liter.}$$

2. $$\text{Average number of cells per liter} \times \text{number of liters under 0.1 square meter to depth sampled} = \text{Total number of cells under 0.1 square meter.}$$

In the case of the vertical hauls the catches should approximate the desired value directly (since the nets were practically 0.1 square meter in diameter) were it not for, (*a*) the failure of even the finest meshed silk to retain the smallest cells, and (*b*) the reduction in straining efficiency that results as the meshes become clogged. In the present case the parallel tests tabulated below have shown that the total catches were seriously affected by both these factors, and especially by clogging. In rich areas in fact, the nets caught on the average only about 1% as many cells per column as did the water bottles; about 2% as many in areas where the flora was somewhat less dense; and not over about 10% as many in regions of sparsity. To render the net counts comparable with those of the volumetric samples, those of 10 thousand to 5 million per 0.1 square meter were therefore multiplied by 10; those of 5 to 9 million by 50; and those over 9 million by 100.

TOTAL NUMBER OF CELLS PER COLUMN

Location of Station	Net Catch		Precipitation Method
	Uncorrected	Corrected	
Off Cape Elizabeth	8,940,000	447,000,000	504,000,000
Western Basin (north)	152,329	1,523,000	970,000
Off Mt. Desert Island	32,388,600	3,238,800,000	2,000,000,000
Off western Nova Scotia	27,007,750	2,700,000,000	1,700,000,000
Eastern Basin	53,162,000	5,316,000,000	5,375,000,000
Eastern Basin	21,213,360	2,121,336,000	2,176,500,000
Northern Channel	9,199,280	919,928,000	1,778,000,000
Eastern Channel	38,250	380,000	1,700,000
Southern Channel	29,260	290,000	852,000
Off northern tip of Cape Cod	73,000	730,000	900,000
Western Basin (south)	1,125,000	11,250,000	13,000,000
Off Cape Elizabeth	6,750	67,500	192,000
Western Basin (north)	92,000	920,000	1,000,000

Reliability of Results

In evaluating the reliability of results drawn from data of the sorts just listed, the adequacy of the regional sampling, i.e. whether the stations were sufficiently close together, is perhaps the most important question, it being well known that the distribution of the phytoplankton may be very irregular with sharp contrasts in abundance within short distances, and especially so during periods of active multiplication. Instances for the Gulf of Maine are given on page 160. Hence the criticism might be made that stations as far apart as ours might fail to reveal such conditions. In the Gulf, however, a marked streakiness occurs most often in shoal water, the plankton being much more uniformly distributed in the deeper bowl outside the 100-meter contour, where it may in fact be essentially uniform over large areas (Bigelow, 1926, p. 403). The uniformity of the gradation from regions of high counts to those of low for the open Gulf shown on the chart for the month when counts were highest (Fig. 2) and when, consequently, the greatest streakiness was to be expected, with the generally close correspondence between the counts for 1933–1934 and those earlier recorded, appears to us to justify the conclusion that the grid of stations was sufficiently close in that year to reveal at least the major variations in the phytoplankton, regional as well as secular.

Errors inherent in the calculations of numbers probably average about 10% for the water-bottle collections (Steemann Nielsen, 1938), at least for such fractions of the flora as the method yielded.[4] The error may, however, be much wider in individual cases for the net hauls, not only because of the shortcomings inherent in this method of collection now generally recognized, or because of uncertainty as to the precise length of the columns of water fished, resulting from deviations from the vertical due to the drift of the ship, but especially because of the incalculable error introduced in our attempt to adjust the results of the net catches to correspond with those of the water-bottles, as stated above. The fact, however, that counts per 0.1 square meter for the northern part of the gulf for the spring of 1932, calculated from Gran and Braarud's (1935) table, correspond closely with our adjusted counts at neighboring localities at that same season (of the spring maximum) in 1934, suggest that the general picture yielded by these is essentially correct. Furthermore, since the probable error varies inversely as the number of organisms per sample, it should be least during the spring maximum, and even if the error in any individual case were as great as 1000%, of which there is small liklihood, the final picture would be little altered.

Numerical Occurrence of Phytoplankton (Diatoms, Peridinians, Coccolithophorids and Silicoflagellates)

We may anticipate the second part of this report (Lillick, 1940) by pointing out that the data for 1934 corroborate the joint evidence of earlier years, to the effect that in the Gulf of Maine the major fluctuations in the total number of planktonic plant cells in the water, regional and seasonal, are due chiefly to fluctuations in the abundance of diatoms, with peridinians, coccoliths and other groups playing only a secondary rôle.

[4] One criticism of the precipitation method for taxonomic investigations is that many of the more delicate organisms are distorted beyond recognition.

Winter Minimum

Previous observations had already shown that in the Gulf of Maine, as in boreal seas generally, inshore as well as offshore, the planktonic flora (chiefly of diatoms) is not only sparse from late autumn through the winter, but also that it is the most nearly constant in abundance at that time of year. In Massachusetts Bay, for example, the flora proved very scanty throughout the winter of 1912–1913, contrasted with the abundant flowering that took place early in the subsequent spring (Bigelow, 1914a). Fritz's (1921) and Davidson's

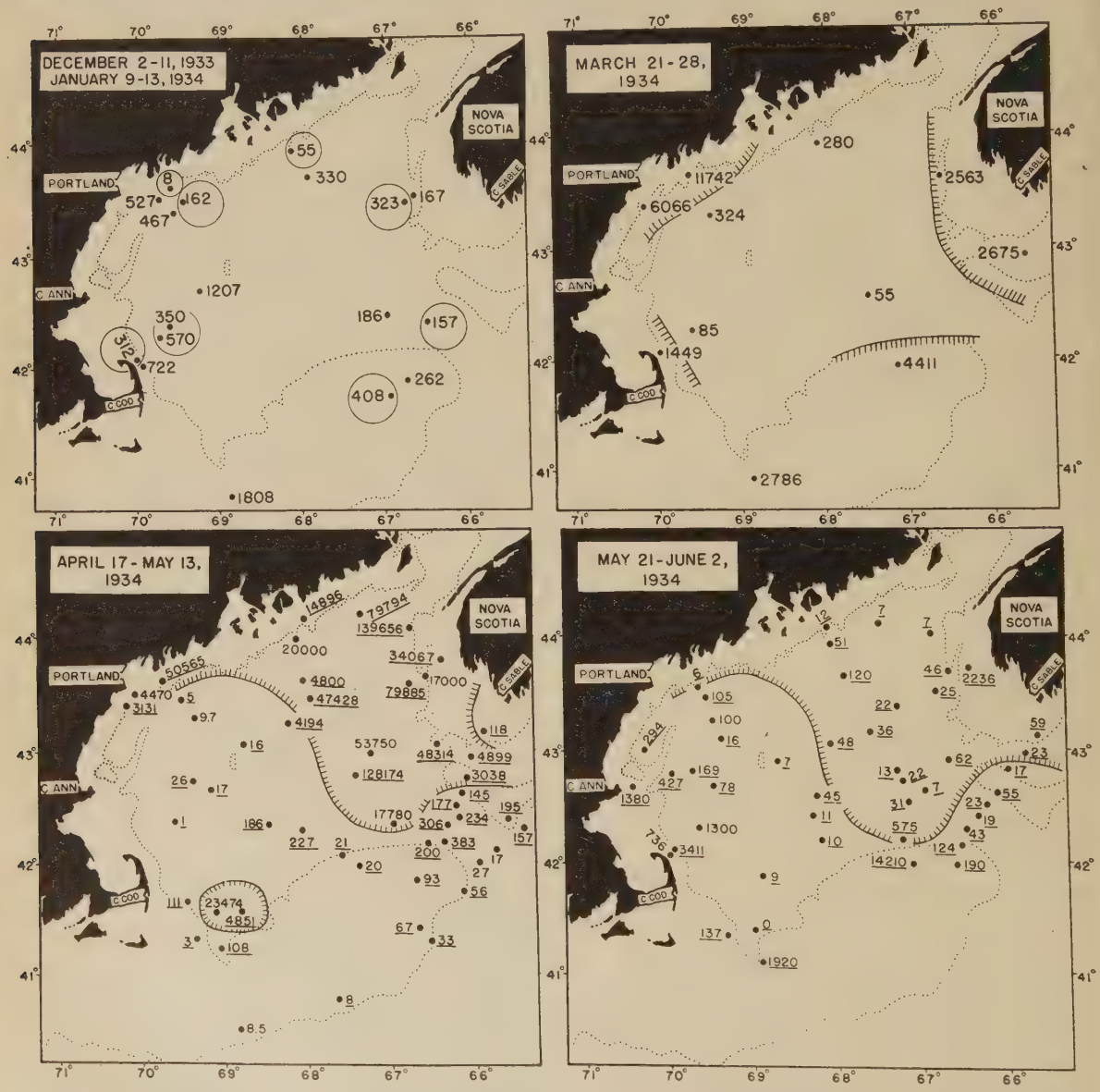

Fig. 2. Numbers of phytoplankton cells, in tens of thousands, for December (encircled), January and March, and May–June; and in hundreds of thousands for April–May, 1933–1934, per 0 1 square meter of sea surface. Counts based on vertical hauls are underlined. Hatched boundaries enclose areas where greatest change took place since the preceding cruise.

(1934) more recent towings in the shallow waters of Passamoquoddy Bay tributary to the Bay of Fundy yielded similar results, namely much smaller quantities generally in early and midwinter than at other seasons in each year of record. When opportunity came in 1920–1921 to reconnoitre the gulf as a whole, it proved that these localities in its opposite sides typify not only the coastwise belt as a whole in this respect, but in all probability the shoal waters of George's Bank as well (Bigelow, 1926). In the deep central basin, however, the absolute yearly minimum falls in late spring after the eclipse of the vernal outburst (p. 161).

The water-bottle samples for 1933–1934 corroborate this picture of winter scarcity, since the counts for December and January combined average only 4,171,000 cells per column (18 stations, Fig. 2),[5] contrasted with an average of more than one billion per column in late April and early May (Fig. 2). In the bowl of the gulf generally, outside the 100-meter contour, averages of 1,500,000 for December (5 stations) and 5,081,000 for January (5 stations), but 1,863,000 only for March (4 stations) suggest some slight increase in production for midwinter, followed by a decline to approximately the early winter level (see also Part II of this report). In the western coastal belt, however, counts at two stations of 80,000 and of 3,120,000 in December, but of 5,269,000 and 7,216,000 in January, and of 117,425,000 and 14,493,000 in March, point to a definite early winter minimum, followed by a slight but unmistakeable increase in plant cells through the late winter. This appears to apply equally to the waters southward across the southern rim of the gulf, judging from counts there of 18 million in January and 28 million in March (no data for December). Local flowerings may, however, develop in shoal water close to land even in early midwinter, witness the record in 1925 of "a rich flowering of *Rhizosolenia alata* from the middle of December (appearing between the 10th and 15th) through January" in Cape Cod Bay (Bigelow, 1926, p. 396) and of Chaetoceros in abundance in Ipswich Bay, a few miles north of Cape Ann, on January 30, 1913 (Bigelow, 1914a, p. 405; 1926, p. 395). The fact that so short a record of observation should have revealed these flowerings is evidence that temporary enrichment of the water with planktonic vegetation is not an exceptional event in shoal water even at that season, when phytoplankton is usually scarce. In the eastern coastal waters and on the eastern part of George's Bank the few available counts were only slightly more than half as large for January (2 million to 3 million) as for December (3 million to 4 million), though again considerably larger for March (26 million to 44 million). Davidson's (1934, Fig. 4) graph of average monthly fluctuations in diatoms similarly shows the minimum as falling in January or February more often (4 years) than in November or December (2 years).

If combinations of the years of record can be taken as representative, it thus appears that the minimum falls a month or so earlier, and is sooner succeeded by an appreciable enrichment of the flora, in the western coastal belt and thence southward than in the basin generally, in the eastern coastal belt, or on the eastern part of George's Bank. Unfortunately, we lack pertinent data in this respect for the northern coastal belt, but if Passomoquoddy Bay can be taken as representative of it, as seems reasonable, it stands intermediate between the two extremes just outlined. By Davidson's (1934) data, however, the precise

[5] The observations are so few in number for December and for January that the combination of the data for the two months probably gives a more reliable picture than would those for either one if taken separately.

date when the winter flora is the most scanty may be expected to vary by as much as three months from year to year at any given locality in inshore waters—from early December to February in Passamoquoddy Bay where her towings were made. We have no information as to how the range of annual variation compares with this in the offshore waters of the gulf.

We may note in passing that the lowest winter count recorded in 1933–1934 was 80,000 per column (Fig. 2), the highest about 18 million (Fig. 2), the next highest about 7 million.

Vernal Flowerings

The early and midwinter flowerings noted above (p. 155) for the western coastal belt appear to have been sporadic events, since the diatoms concerned were not those responsible for the vernal outburst,[6] and it is certain that the more productive of the two was restricted to a small area, as described elsewhere (Bigelow, 1926, p. 396). A significant increase in the number of vegetable cells took place, however, in Massachusetts Bay (representative of the western coastal belt) in 1913 between February 13th and the 4th of March (Bigelow, 1914a, p. 408). In 1920 (Bigelow, 1926, Fig. 108) there were considerable quantities (up to 290 cc. per haul) of diatoms by March 4 in the coastal belt off Portland, Maine, where (by other evidence) no richer flora is to be expected in January or February than elsewhere around the coast line of the gulf. And again in 1934, the counts were significantly larger for the last week in March than for January at each of the three stations in the western coastal belt where data were obtained in both these months (Fig. 2).

Fritz (1921) likewise records considerably larger catches for March than for January–February in Passamoquoddy Bay [7] for the year 1916, and Davidson (1934) described the multiplication of diatoms as commencing there as early as February in one year (1931), and in March in four years, though not until April in one (1925), for the periods 1925–1928 and 1930–1931.[8] As a result, perhaps, of the discharge from Passamoquoddy Bay, Davidson's (1934) curves similarly show a rapid increase (of diatoms) in March at her station (No. 5) just off its mouth in each of the five years (1926–1928; 1930–1931), consistent with counts by Gran and Braarud (1935) corresponding to about 12,393,000 cells per column at this same general locality on March 5 of 1932.[9] It appears that vernal enrichment does not involve the waters of the open Bay of Fundy generally until somewhat later in the season, for Gran and Braarud describe the phytoplankton there as still continuing very scanty in March. The limits of the richer and poorer subdivisions of the Bay were, in fact, rather precise at the time though somewhat spotty (Gran and Braarud, 1935, p. 333, Fig. 35).

We may conclude from the foregoing that active multiplication of the phytoplankton is ordinarily in progress in the western coastal belt on the one hand, and in the waters tributary to the Bay of Fundy on the other, by early March or by the end of the month at latest. The evidence of 1920 points to the general vicinity of Cape Elizabeth as the site of the earliest outburst of all, since on the fourth of the month in that year the tow yielded

[6] See Part II of this report (Lillick, 1940) for description of the qualitative composition of the flora from season to season.

[7] Fritz (1921, pp. 50–52) reports averages of 13,200 cells per tow for February (2 stations) but of 112,525 per tow for March (4 stations).

[8] Data for the critical season are lacking for 1929.

[9] Average of 1549 per liter for the several sampling levels combined.

290 cc. there, but only 5–8 cc. off Massachusetts Bay to the south and 2 cc. near Mt. Desert Island to the east, a distribution which is at least consistent with the fact that a considerably larger count was recorded off Cape Elizabeth than near Cape Cod in late March of 1934 (Fig. 2). The few available data (for 1920 and 1934) suggest that flowerings may be expected to develop equally early on the western part of George's Bank.

Lacking coincident data both for the Massachusetts Bay region and for Passamoquoddy Bay in any one year, we have no basis for judging whether the difference in latitude between these two localities is accompanied by a corresponding difference in the date of inception of active vernal flowering. Actually this event has been recorded as early (February) in the more northern of these two localities in the year of record when it fell earliest there (1931), as in the more southern (late February in 1925, see above). An appreciable increase in the phytoplankton may also occur equally early in some years along the eastern coastal belt to the southward of Nova Scotia and on the eastern part of George's Bank, as happened in 1934 when (at the pertinent stations) the count was between twelve and thirteen times as great there in the last week in March (26–44 million) as it had been two months previously (about 2–3 million, Fig. 2). However, the fact that the phytoplankton still continued minimal in this same general region as late as the 23rd of March in 1920 (Bigelow, 1926, Fig. 108) is evidence that a variation of a month or more is to be expected there in the spring outburst from year to year. The small counts recorded for the bowl of the gulf generally outside the 200-meter contour for late March of 1934 (from 550,000 to about 3 million cells per column, Fig. 2), added to the correspondingly small volumes yielded there by the towings in this same month of 1920 (Bigelow, 1926, Fig. 108), make it unlikely that active flowerings ever develop anywhere in that general subdivision of the gulf before April in normal years. Furthermore it may prove that this applies equally to the northern coastal belt between Penobscot Bay and the Bay of Fundy, since the volumes of phytoplankton were still minimal there at 2 stations on March 3 and March 22 in 1920 (Bigelow, 1926, Fig. 108); but no data are available for that particular sector at the critical season in any other year.

The regional and annual variations outlined above, added to the lack of data at critical localities and dates, make it difficult to present a coherent picture of the development of the vernal flowerings which can be taken as characteristic of a normal year. It is, however, clear that the peak may be reached at the mouth of Massachusetts Bay as early as the end of March in some years, as happened in 1938 and again in 1939, when a great abundance of diatoms in the last half of the month was followed by a rapid decline by the first week in April (unpublished data). In other years, on the other hand, great numbers of diatoms may persist there as late as the third week of April; in 1920, for example, the catch was as large there (200 cc.) on April 20th as it had been on the 6th (190 cc.). Lacking pertinent data for 1934, the first week in April might be set as the normal expectation for this point in the seasonal cycle in this particular region.

Cape Ann appears, however, to mark a natural division in this respect, because in 1913 diatoms continued extremely abundant near the Isles of Shoals some 20 miles north of the cape until at least the first week in May (Bigelow, 1914a), i.e. until some 2–3 weeks later than is likely to be the case just south of the cape. Again in 1915 diatoms were swarming all along the coast inshore as well as offshore from the vicinity of Portland to the Grand Manan Channel as late as May 10–13 (Bigelow, 1917, p. 324, Fig. 98). Similarly in 1934,

5 billion cells per column were recorded off Portland as late as the third week in April, and 50–60 million per column near Cape Elizabeth, while the fact that the nitrates and phosphates had declined at these stations (on the average) to 5–20 mgs. and 34–36 mgs., respectively, from 100 ± mgs. of nitrate and 100 ± mgs. (at 1 meter) of phosphate in March, suggests that the actual peak of phytoplankton abundance had passed some days earlier. Counts of 1–3 billion were also recorded in the coastal waters near Mt. Desert Island in that same month of 1932,[10] with 356 million cells per column on April 29. In Passamoquoddy Bay, Fritz's (1921), Davidson's (1934), and Gran and Braarud's (1935) counts show the vernal outburst as reaching its climax rarely as early as April (about 4 billion cells per column at one station on April 25, 1932, as calculated from Gran and Braarud's counts), but usually not until May. Available data suggest that the climax is not ordinarily reached in the open Bay of Fundy until several weeks later, for Davidson's (1934) curves for her station off the mouth of Passamoquoddy Bay show the peak as falling in June in four years of her series, and late in May in a fifth. Gran and Braarud (1935, p. 339), however, describe an "extreme decline in phytoplankton" from May to June for the Bay of Fundy in a year (1932) when a rich flora (though perhaps not the extreme peak) had developed in Passamoquoddy Bay in April, as remarked above.

Continuing around the Gulf, the data for 1934 show a great abundance of phytoplankton in the last half of April throughout the northeast part generally, including both the coastal waters off western Nova Scotia, and the eastern part of the basin (Fig. 2); locally also off southern Nova Scotia and out to Brown's Bank (though interspersed with relatively barren localities) early in that May.

Unfortunately the data do not serve accurately to trace the development of the spring flowering for any part of George's Bank or for the western arm of the basin of the Gulf. Pertinent records for the western part of the bank are, (*a*) a catch of 200 cc. (moderately rich) on February 22, 1922 (Bigelow, 1926, p. 399, Fig. 108); (*b*) a rich diatom plankton there on April 26–27, 1913 (Bigelow, 1914a, p. 415); and (*c*) counts of 28 million in March (1 station, Fig. 2), 9 million and 230 thousand in early May, and 15 million in late May of 1934 (Fig. 2). These, combined with the fact that the supply of nitrates and phosphates was considerably lower there in May of that year than in March (Figs. 5, 7), point to April as probably the season of most active production.

The distribution of nutrient salts also suggests a much greater abundance of phytoplankton in April for the eastern part of the Bank (no counts available) than either in March (1 station, 44 million) or in early May (7 stations, average, 5 million; maximum, 6 million), since nitrates declined from 135 mgs. to 4–10 mgs. (Fig. 7). In this instance too, we find corroborative evidence from the year 1913, when the phytoplankton in the same general region (Lat. 41° 37′ N., Long. 67° 18′ W.) was so rich on April 26–27 that "the nets soon clogged, although of large mesh" (Bigelow, 1914a, p. 415).

In the southern arm of the western basin in 1934 rich counts were recorded in late April (2 billion) and early May (485 million); whereas in its northern extension the counts for late April (four stations) were slightly smaller even than at one station in March (Fig. 2), and the supply of nitrates and phosphates was about the same (Figs. 5, 7). The fact, however, that the nitrates were greatly reduced there by late May (Fig. 7) when the phytoplankton was even more sparse than it had been a month earlier, suggests that a

[10] Calculated from the numbers per liter at different levels reported by Gran and Braarud (1935).

peak of abundance had developed and passed by, in the interim between the late April and late May cruises. This is supported by evidence from 1915 when diatoms were still swarming on May 4–14 "over a triangular area in the central part of the gulf extending from Cape Elizabeth to the Grand Manan Channel, and from the coast of Maine at least as far as Cashes Ledge" (Bigelow, 1917, p. 324, Fig. 98). In fact at one station there diatoms were so plentiful on May 4 "that every interstice of the fine net was clogged and its silken bag transformed into a cone of slime almost impervious to water after a few minutes' submergence," the coarse meshed net yielding over 2000 cc. in 20 minutes (Bigelow, 1917, p. 344). In short, it appears by present evidence that the vernal outburst may be expected by the last week in April in the southern part of the western basin, but not until well into May in its northern extension.

It was on the late April 1934 cruise that the largest phytoplankton count was recorded at the level of maximum abundance, i.e., 1,162,000 per liter at 10 meters at a station in the east central part of the basin, where the calculated number per column was about 5,375,000,000. This contrasts with a minimum at the level of greatest abundance (in this case the surface) of only 220 cells per liter in December 1933 in the southwestern part of the basin.

Regional Abundance of Vegetation at the Climax of the Vernal Outburst

Available data on regional abundance at the climax of the vernal outburst for different localities are:

Locality	Year	Cells per Column
Off Gloucester, Massachusetts	1939	> 2 billion
Coastal belt near Portland, Maine	1934	400–5000 million
Vicinity of Mt. Desert Island	1932	6 billion
Vicinity of Mt. Desert Island	1934	2 billion
Passamoquoddy Bay	1932	4 billion
Mouth of the Bay of Fundy	1932	6 billion
Northeastern part of the gulf generally, including basin as well as coastal shelf	1934	
Average of 9 stations		7 billion
Maximum		14 billion
8 of the stations		> 3 billion
Western arm of basin, southern part		2 billion

The foregoing, contrasted with the mid- or late winter values shown on Fig. 2, indicates that a 1000-fold multiplication of vegetable cells is usual from the winter minimum to the vernal peak in all major subdivisions of the Gulf where the phytoplankton has been sampled near the time when the vernal outburst reaches its climax. The maximum increase for any one locality was, in fact, 60,000 fold, i.e., a few miles east of Portland where the count per column rose from 80,000 cells in December to 5 billion in April (Fig. 2), and for all that is known to the contrary, this may apply equally to the waters of George's Bank where data are lacking at the critical season. As a result of variations in the dates at which the maxima develop and in the rate at which the flora is subsequently impoverished in different parts of

the Gulf, the regional variations in abundance are wider throughout the spring than at any other time of year.

We must, however, warn the reader that although rich catches are the rule during the season of active flowering, wide variations in the amounts present have frequently been recorded within a few miles; the planktonic flora may even be "so streaky that one can actually see the net pass through alternate bands of brownish diatoms and of clear water" (Bigelow, 1926, p. 403). A similar patchiness was observed off Gloucester, Massachusetts, in early April of 1939, and on the eastern part of George's Bank in April, 1913. There is, of course, nothing novel in the observations that the distribution of the phytoplankton may be so very irregular, for this has often been reported in the shoal water of other seas (Bigelow, 1914a, p. 415). No doubt the fact that very poor catches are occasionally recorded in regions and at times when the counts are generally high, is explicable on this basis. In fact, the distributional chart for late April (Fig. 2) affords one example, i.e., a count of less than 100,000 at one station in the western basin, when all other counts were larger than 1 million.

The range of regional variation in the maximum number of cells that have so far been recorded in the several major subdivisions of the open Gulf at the respective seasons when the vernal outburst of diatoms is near culmination, is only in the ratio of 1 to about 6 or 7; or about 2 billion, contrasted with about 13 billion (Fig. 2). This ratio is perhaps no wider than can be charged to the roughness of our methods, coupled with the chance distribution of the sampling stations, it remaining doubtful whether any station has been sampled when cells were actually the most plentiful there. In the face of this uniformity of results, no one subdivision of the gulf can be classed as significantly more productive than another at the season when the vernal vegetation is most abundant. The Bay of Fundy stands out, however, as a notable exception in this respect, for even though the maximum counts that have been recorded near its mouth are of about the same order of magnitude as for other parts of the Gulf of Maine area, Gran and Braarud (1935) found that the waters of the inner parts of the Bay are far less rich even at the peak season. And it is largely on the basis of this regional contrast that they have based their interesting discussion of factors limiting the production of phytoplankton within the Bay.

The preceding statement that the maximum abundance of phytoplankton is at least of the same general order of magnitude throughout the open Gulf as a whole, should not be taken as implying that the total productivity of the vernal flowerings is equally uniform regionally, for it is necessary to take equally into account the notable contrasts in the duration of the period of abundance of phytoplankton in different localities. In Massachusetts Bay (to recapitulate) this may be only a few days, but several weeks along the coast eastward from Mt. Desert Island, and 1–3 months in Passamoquoddy Bay.

Were we forced to rely on the counts of total phytoplankton alone, we would meet an impasse here, because of uncertainty as to the relative degree to which the persistence of a rich flora in any given locality—Passamoquoddy Bay, for example—may depend on continued multiplication of cells (though at a declining rate) and to what degree on a long period of survival, after the climax of abundance is reached. Neither does Davidson's (1934) analysis of the flora help in this respect, for the same two genera—Thalassiosira and Chaetoceros—that constitute the great majority of the persistant planktonic flora of Passamoquoddy Bay after the vernal climax, are the same two that are chiefly responsible for the development of the latter. Granting these uncertainties it seems, however, per-

missible to conclude that where diatoms persist at a high and roughly constant level of abundance for as much as 4–12 weeks after the period of rapid multiplication has terminated, as happens in Passamoquoddy Bay, at least a moderate amount of production is taking place; whereas production must be practically at an end after the climax, in regions where the latter is succeeded by as rapid an impoverishment as it is in most other parts of the Gulf. On this basis, the western coastal belt and the bowl of the Gulf generally would rank relatively low in productivity for the vernal half year as a whole, the northern coastal belt and Passamoquoddy Bay relatively high, also George's Bank; but to attempt any numerical comparison of the relative productivity of these contrasting regions, would be idle from existing data.

Late Spring

Preliminary observations for 1915 had already suggested that the vernal peak of production is followed by a decrease hardly less sensational throughout the deep offshore waters of the Gulf as a whole. This is corroborated by the data for late May of 1934, when four counts only were as large as one million cells per column among 33 stations distributed over the central bowl outside the 100-meter curve, and from southern Nova Scotia out across the Northern Channel and Browns Bank to the Eastern Channel. Inasmuch as these four were all located on the western side, they no doubt represent the zone of transition to the somewhat richer flora that still persisted in the neighboring coastal belt (Fig. 2). The severity of this impoverishment may be more precisely illustrated by the fact that the late May average for the deep offshore water (27 stations average 834,000) was only about 1/4000 as great as the average for the same general localities for April (3,417,362,000). In fact, the May average for the part of the Gulf in question was only about 1/4 as great as the winter average (3,147,000), a fact interesting because the winter, prior to the vernal enrichment, is usually regarded as the season of greatest planktonic poverty.

Seasonal impoverishment after the vernal climax is also extreme—if perhaps somewhat less so—in most years in the western coastal belt, as exemplified by stations near Cape Ann and Cape Cod. In 1912, 1915, 1938 and 1939, for example, the vernal peaks—when cells are to be numbered by the billions—were shortly succeeded near Cape Ann by the disappearance of the diatoms and their replacement by a very much sparser peridinian flora. However, counts of 34 million cells per column close to Cape Cod, and of 2 and 11 million near Cape Ann, as late as the last week of May in 1934 (no data for April) show that at least a moderately rich flora may persist several weeks later in some years than in others on this side of the Gulf. And although diatoms practically vanished from these waters early in April in 1920, the impoverishment of the flora as a whole which usually accompanies that event was somewhat delayed in that particular year by a great development of Phaeocystis about the middle of the month;[11] however, this flowering persisted only briefly, Phaeocystis having completely vanished by the 4th of May. Inasmuch as this is our only record for such a flowering in the Gulf, it is probable that such events are sporadic and not a normal stage in the seasonal succession.

Contrasting sharply with the impoverishment, more or less severe, that follows the vernal outburst in the parts of the Gulf just discussed, an abundant flora appears to persist at least locally, until well into the summer in the northeast coastal zone in most years, and

[11] Actual records, April 18–20 (Bigelow, 1926, p. 458).

in waters tributary to the Bay of Fundy. A rich diatom flora was recorded close to Mt. Desert Island, for example, on June 14 of 1915 (no counts were made), and there were 6 billion [12] there on June 28th of 1932, or more than 25 times as many as off Casco Bay some 90 miles to the westward.

Similarly, Davidson (1934, p. 9) found a high level of abundance, though with fluctuations, persisting in Passamoquoddy Bay for several weeks after the vernal climax with "the largest maximum following towards the end of June or in early July," which is in line with Gran and Braarud's (1935) record corresponding to some 600 million cells per column there on June 20th, and of 4 billion on July 30 of 1932. Diatoms also persist longer in abundance in the Bay of Fundy itself than in the open waters of the Gulf to the southward though not as late as in its tributaries, to judge from Gran and Braarud's (1935) counts corresponding to nearly 6 billion per column there on May 23 of 1932. And although they describe an "extreme decline in the phytoplankton" as taking place in the Bay from May to June (Gran and Braarud, 1935, p. 339), the numbers they record at 3 Fundian stations in the latter month (corresponding to 18, 38, and 102 million cells per column, respectively), while much lower than for May, are nevertheless considerably higher than the counts for the open Gulf outside the coastal belt for late May and early June of 1934 (Fig. 2). The available data similarly suggest that a moderate flora, though less rich than the probable April peak, may be expected to persist into early summer in the turbulent waters of George's Bank, to judge from occasional counts of 1–8 million there in early May and of 142 million for late May of 1934 (Fig. 2). Unfortunately we lack numerical data for the extreme regions during the critical season of any one year; therefore it is impossible to calculate the ratios of regional variation, but if the picture for the open Gulf for 1934 is comparable with Gran and Braarud's (1935) counts for 1932, the vicinity of Mt. Desert Island and Passamoquoddy Bay may be expected to support something like two thousand times as rich a flora at the end of May, as does the deep central bowl of the Gulf generally or the waters southward from Nova Scotia.

Summer

The evidence for 1933 and 1934 combined (Fig. 3), is that the planktonic flora of the bowl of the Gulf—at its lowest ebb late in May (average only 834,000 cells per column, p. 161)—may be expected to increase somewhat in numerical abundance through June, counts at 16 stations outside the 200-meter curve having averaged 5,478,000 in the first week of July of 1933, an indication of a 6-fold multiplication in the number of vegetable cells present. This increase, it appears, normally continues through late July, again on the assumption that combination of data for different years be allowable, for Gran (1933) reports counts corresponding to 51–543 million cells per column (average about 272 million) at four stations in the bowl early in August of 1932, or about 50 times as many as were recorded there for early July of 1933 (Fig. 3). Centers of great richness for *Pontosphaera Huxleyi* may also develop locally in the deeper parts of the Gulf in midsummer, witness counts corresponding to 758 million of these tiny plants per column in the southeastern part of the basin on July 16, 1933 (Braarud, 1934).

There is, however, no reason to suppose that this midsummer flowering in the bowl ever approaches in richness the flora that develops there at the time of the vernal peak;

[12] Calculated from an average of 809,946 cells per liter (Gran and Braarud, 1935, p. 452).

the largest August count yet recorded there (543,000,000) is, in fact, only about 1/26 as large as the maximum for April; and the average for the one month only about 1/1630 as great as that for the latter. And the counts at 7 stations outside the 100-meter contour were significantly smaller (2–41 million, average about 10 million) in September of 1934—the one year of record—in fact only about 1/27 as great on the average as the August count just mentioned. It appears, in short, that the extreme impoverishment that follows the vernal outbursts of diatoms in the bowl of the Gulf in general is normally succeeded there by a second, but less active flowering of phytoplankton in mid- and late summer.

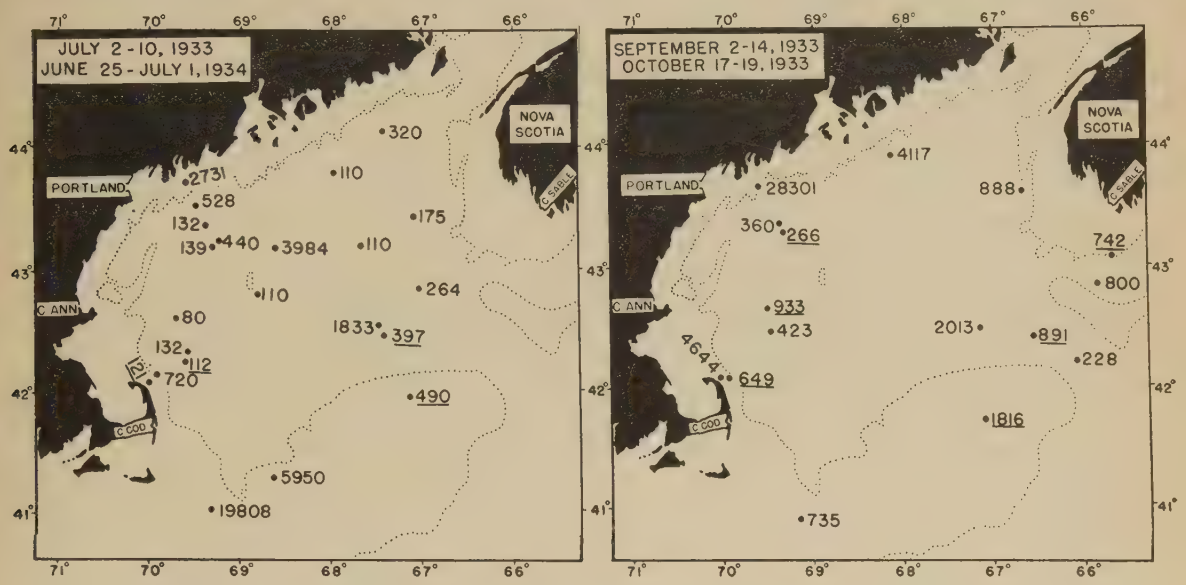

Fig. 3. Numbers of phytoplankton cells (in tens of thousands) per 0.1 square meter of sea surface. The values for June–July 1934 and for October 1933 are underlined.

It also seems well established that a summer or early-autumn flowering of diatoms takes place generally in the shoaler waters along the coast—one, however, which, by present data, may vary widely from place to place in the dates of its inception, and culmination, as well as in its productivity. Sceletonema was, for example, recorded in abundance in Massachusetts Bay late in September of 1915 (Bigelow, 1917, p. 326; 1926, p. 404); so abundantly, in fact, that the average catches there had risen to 25–30 cc. per haul, contrasted with only 2–3 cc. at a neighboring locality a month earlier. And a September maximum is also indicated for the coastal water a few miles east of Portland, by a count there of about 280 million cells per column on the 6th of the month in 1933 (Fig. 3), for which *Guinardia flaccida* was responsible (Lillick, 1940). Again, a tremendous August flowering of Asterionella (no counts obtained) was encountered near Mt. Desert Island in 1912, extending thence coastwise both eastward and westward for perhaps 30 miles (Bigelow, 1914, p. 133, 1926, p. 431). In 1932 there were 332,000 vegetable cells per liter at the richest level, and an average corresponding to 359 million cells per column, a few miles off Mt. Desert Island on August 14 (Gran and Braarud, 1935), where there had been only about 1 million per column in the last days of the previous June. Burkholder's (1933) data for 1930, strongly suggest—if they do not prove—a definite maximum for diatoms in

Frenchman's Bay between Mt. Desert Island and the mainland during late August. Davidson (1934) has similarly reported an August maximum, more or less well defined, following a decline in July, in 5 out of the 7 years of record for Passamoquoddy Bay, where Gran and Braarud (1935) also had counts corresponding to about 1047 million cells per column on August 16, 1932. Davidson's (1934) curves for a station (No. 5) just outside the mouth of Passamoquoddy Bay show, it is true, the opposite state, i.e., progressive impoverishment after the passage of the vernal climax in each year of record. However, the failure of a second flowering to develop just then is seemingly a local phenomenon, for Gran and Braarud's (1935) counts point to an August flora of at least 500–600 million cells per column across the mouth of the Bay of Fundy, for diatoms alone.

Counts of phytoplankton for the coastal shelf west and south of Nova Scotia, for Brown's Bank and for the Eastern Channel are lacking for July and August; nor is any information available as to the supply of nutrients there for those months. Hence, it is not possible to deduce from the September counts of 2 and 9 million cells (Fig. 3), whether this comparatively sparse flora had or had not been preceded by an August peak of production. High counts have, however, been recorded locally on George's Bank on two occasions in mid- and late summer, corresponding respectively to about 2,814 million on the eastern part on August 2–4, 1932 (Gran, 1933), and to 198 million on the western part in early July 1933 (Fig. 3). An abundance of diatoms were also encountered, but no counts obtained, on the western end of the Bank on July 9 in 1913, on its northeastern edge on July 23 in 1914, and at 2 stations on the western end on July 23 in 1916 (Bigelow, 1926, p. 391). At least moderately rich production of diatoms is thus to be expected, as earlier surmised, over one part of the Bank or another at any time in July or August, either confined to small areas, as was the case in July of 1914 (Bigelow, 1917), or more widespread, as in the first half of July of 1933 when the flora appears to have been at least moderately rich over the Bank as a whole.

It appears, however, that these summer flowerings on George's Bank are decidedly irregular events, and that they involve the water of the Bank much more generally in some years than in others. Neither is it "yet clear whether any particular region on the Banks is more favorable for the multiplication of diatoms than another, except that we have always found these rich flowerings on its shoaler parts and never close enough to the continental slope to be within the influence of the high temperature outside the edge" (Bigelow, 1926, p. 391). A rich flora may also exist—with what regularity is not known—in late summer or early autumn over Nantucket Shoals farther west as previously noted, Dr. W. C. Kendall having written "in his field notes that 'on September 2, 1896, the water was very full of brown slimy stuff' at latitude 40° 47′, longitude 69° 43′, which can only have been diatoms" (Bigelow, 1926, p. 391).

In the western coastal belt, where a decided impoverishment succeeds the spring peak, this second period of enrichment resulted in a second and rather prominent peak in the only year when it has come under observation (p. 163). Along the northern coasts of the Gulf, however, and in the Bay of Fundy this may or may not be the case, depending not only on the productivity of the late summer flowering, but equally on how rich a flora may persist there through late spring and early summer in any particular year, and on what degree of impoverishment may take place prior to the second period of enrichment. Over the shoal southern rim of the Gulf, by present indication, the second period of flowering is

more often made evident by the development of rich centers of circumscribed extent than by a great enrichment involving the waters of George's Bank as a whole.

Available data also suggest significant regional variation in the dates when the second flowering reaches its climax; i.e. that this is to be expected by August in the northern side of the Gulf including the Bay of Fundy, on the one hand,[13] also locally on George's Bank and in the southwestern part of the basin on the other, whereas we have no record of it in the Massachusetts Bay region until a month later.

Autumn

Information as to the numerical abundance of phytoplankton throughout the autumn, subsequent to the second flowering period (the latter falling in late summer or early autumn, depending on the locality), is limited to the counts for September and October shown on figure 3, to the results of towings in the region of Passamoquoddy Bay (Fritz, 1921; Davidson, 1934) and to a few November towings off Gloucester in 1912 (the latter summarized by Bigelow, 1926, p. 395).

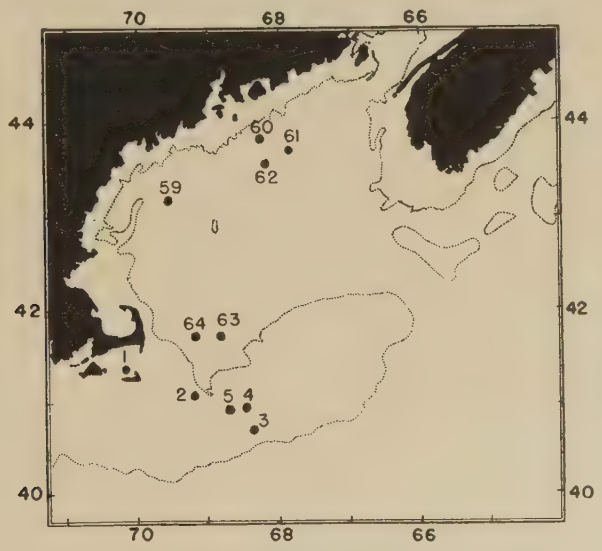

Fig. 4. Locations of Atlantis stations, August, 1936.

In Passamoquoddy Bay in each of the years when the second flowering developed as early as August (e.g., 1927, 1928, 1931, Davidson, 1934) it was followed either by a rapid depletion leading to a very low level of abundance by the end of the month, or at least by a decline continuing as late into September as the observations were made. Numerical data for the Bay are lacking for the later autumn, but the history of events elsewhere makes it likely that in years when the second enrichment endures there into September, or throughout that month, e.g., 1917, 1925, 1926 (Bailey, 1917; McMurrich, in Bigelow, 1926; Davidson, 1934), impoverishment follows soon thereafter. The chief annual differences in this respect for the Bay are in the date at which impoverishment commences, and in its severity. Average counts corresponding to about 95 million cells (6 stations, maximum,

[13] Horizontal tows in August, 1936 yielded an abundance of diatoms at the stations marked on Fig. 4.

363 million) for the open Bay of Fundy for September 10–15 of 1932 (Gran and Braarud, 1935, Tables), contrasted with the comparatively high counts of the previous month (p. 164), again show impoverishment sufficient to have reduced the flora to about 1/5 or 1/6 of the abundance that prevailed there shortly previous.

A similar and coincident depletion is equally indicated for the bowl of the Gulf (outside the 100-meter contour) as a whole—witness counts there equivalent to 51–543 million per column (average, 272,000,000, 4 stations) in August of 1932, but of only 2–41 million (7 stations, average, 10,026,000) in September of 1934, and of 2–9 million in October of that year (Fig. 3). A rather sparse flora (7–18 million) was also recorded then on George's Bank, contrasting with the frequent rich concentrations of mid- and late summer (see above); and although the second flowering may not develop in Massachusetts Bay or in the coastal belt as far north as the offing of Portland until well into September (p. 163), the phytoplankton in the vicinity of Gloucester proved, in 1912, to be very scanty indeed by the last week of November (Bigelow, 1914a, p. 405; 1926, p. 395).

Data are lacking for November for other parts of the Gulf, but the very low counts recorded for December, 1933 (p. 155, Fig. 2) make it extremely unlikely that rich concentrations of phytoplankton of any sort normally develop anywhere in the Gulf in the last two months of autumn. This is corroborated by the fact that in 1920 also "the several species of diatoms that are most abundant from spring to early autumn had practically vanished from the whole coastal belt between Cape Cod and the mouth of the Bay of Fundy by December" (Bigelow, 1926, p. 395)—to be succeeded by Coscinodiscus which has never been found in more than moderate numbers in the Gulf (Lillick, 1940).

Notes on Some Factors Affecting the Abundance of Phytoplankton in the Gulf

It is obvious that the significant fact in regard to abundance is not so much the number of vegetable cells present from time to time—for among different planktonic plants these vary widely in size—but the mass of living matter produced. Even as rough a comparison between numbers of cells and total volumes as available data have so far afforded for the Gulf of Maine has been enough to show that the two are not parallel, though the trend from season to season is similar. It has been suggested that a somewhat better picture may be afforded by measurement of the amount of chlorophyll present and of carotin pigments, per unit volume of water, taken as an index to the production of carbohydrates,[14] a method not yet applied to the Gulf of Maine. Granting all the shortcomings of counts of planktonic plant cells as a basis for studies of production, they do give at least a rough picture of the ups and downs of the planktonic flora from season to season, the range of numerical abundance being so wide as to make it unlikely that the total mass of phytoplankton is ever large, when the number of cells is small, or vice versa. Comparison between the numbers of cells and the amounts of phosphates and nitrates in solution in the water—or any other factor that may be chosen for analysis—seems therefore allowable as a rough index of the degree to which total production of the phytoplankton is correlated with the latter.

Gran and Braarud (1935, p. 404) have already shown, in their investigation of 1932, that "the general changes in the growth and decline of the phytoplankton population of the

[14] For examples of the application of this method and for discussions of its validity, see especially Harvey (1934), Riley (1939, 1939a), Krey (1939), and Gillam, El Ridi, and Wimpenny (1939).

Gulf of Maine . . . agree with the generally adopted theories, that the quantitative variations are governed by the supplies of light and nutrient salts (phosphates and nitrates)" with light, of course, determining the thickness of the productive stratum of water. The data for 1933–1934 not only corroborate this generalization, as was to be expected, but allow a somewhat more precise evaluation of the effects of certain of the factors involved.

Initiation of the Vernal Outburst

The outstanding points to be considered in relation to the planktonic cycle of the Gulf are: first, the stimulus for the vernal outburst of diatoms, and for its occurrence at a particular date; second, the cause of its eclipse after a longer or shorter period of active production; third, the causes for the regional variations that exist in the numerical abundance of the planktonic flora, diatoms and peridinians combined, during the summer and early autumn; and fourth, the causes for autumnal impoverishment of the flora. The factors involved include (1) the chemical, dissolved nutrients,[15] (2) the physical, i.e., light, temperature, activity of vertical circulation, and (3) the degree to which the abundance of planktonic plants is affected by the animals that graze upon them.

The general rule that the diatoms, at least, depend for active flowering on an adequate supply of nutrients in the water is now generally accepted. Equally, however, it has been established that in some parts of the sea active flowerings may not develop until several months after the supply of nutrients has built up to a high level in the depth-zone of plant production. We may state at once that comparison of the cell counts for the year 1933–1934 with the coincident determinations of phosphates and nitrates proves that the Gulf of Maine as a whole falls in that category. To support this generalization it is perhaps enough to point out that the concentrations of nutrient salts were maximal (ca. 138 mgs. of nitrate and 110 mgs. of phosphate (PO_4) per cubic meter, Figs. 5, 7) in the upper strata of the Gulf as a whole in December and January; whereas active flowerings have never been recorded earlier than the beginning of March except in very restricted localities (p. 155). In the occurrence of a lag of this sort and one of such considerable duration, the Gulf agrees with certain Norwegian localities (Føyn, 1929; Gran, 1930; Braarud and Klem, 1928) and with Puget Sound (Gran and Thompson, 1930).

To explain such a situation it has been suggested that vernal flowerings await the increment of nutrients contributed by an inrush of river water (Nathansohn, 1910; Gran, 1933; Bigelow, 1926; Ercegović, 1940). In the Gulf of Maine, however, the entry of fresh water can hardly have been a controlling factor in 1934, for salinities did not reflect any great vernal freshening until May, i.e., not until long after the onset of the spring diatom flowering. It seems still less likely that the late summer flowerings along the north and northwest coasts of the Gulf owe their existence to the nutrients contributed by the drainage of that region, river-discharge being very small in volume at that time of year. Furthermore, rich flowerings occur on George's Bank, far from any immediate influence from this source.

These generalities argue in particular against the view that the vernal outbursts in the Gulf await the soluble iron from the land that may be contributed by the river-freshets of spring. Having no determinations to contribute of the amounts of iron in solution, we need only refer in this connection to Gran's (1933) finding from culture experiments at

[15] For recent discussion of growth requirements of diatoms, see Harvey, 1939.

Woods Hole, that while the addition to the culture of soil extract and of a ferri-ligno-protein did stimulate the reproduction of certain neritic diatoms (*Leptocylindricus danicus*, *Nitzschia seriata*), it did not significantly affect that of the oceanic species, *Rhizosolenia alata*, and the diatom species responsible for the mass flowerings of the Gulf of Maine chiefly belong to the "planktonic" category. Neither do such measurements as have been made of the amounts of silicates in the Gulf of Maine (Bigelow, 1926) or elsewhere, suggest that these are ever apt to be a stimulating or a limiting factor in the Gulf.

In short, our data lead to the general conclusion that though an augmenting flora cannot occur without a sufficiency of nitrates and of phosphates, it usually is not the attainment by these two nutrients, nor of any other [16] of any particular richness in the surface waters that stimulates the vernal outburst of plant cells in the Gulf of Maine.

The sporadic occurrence of rich flowerings of diatoms in Cape Cod Bay in December (p. 155), added to the fact that at Woods Hole the chief diatom maximum comes in that same month in most years (Fish, 1925), is good evidence that in the Gulf—unlike the English Channel (Harvey, 1926; cf. also Marshall and Orr, 1926)—illumination is strong enough for active photosynthesis, even in early winter; as strong in fact, when it is at its minimum for the year, as it is in Norwegian waters in spring, i.e., at the time of the vernal outburst (Kimball, 1928). And the possibility that differential light-requirements for different diatoms enter into this particular case is barred, since the same species are dominant in the Gulf as off Norway. The fact that there is as much as six weeks variation in the dates of the vernal outburst in different parts of the open Gulf—a difference far wider than could be credited to differences in total illumination resulting from the differences in latitude between the stations in question, or from local differences in cloudiness or in the prevalence of fog—is further evidence that the factor delaying the rapid multiplication of diatoms is not any insufficiency of light, except perhaps in the Bay of Fundy, where local conditions are peculiar owing to the high degree of turbidity of the water, as shown by Gran and Braarud (1935).

Neither does it appear that vernal flowerings are conditioned by any particular value of temperature, for the surface waters are somewhat warmer over the Gulf as a whole in December when the phytoplankton is very sparse indeed, than in April, when diatom flowerings are at their height over most parts of the Gulf. It is, of course, possible that a rising temperature has some stimulating effect in the Gulf where the surface cools generally to its yearly minimum about the last of February or the first of March. But without laboring the point we may say at once that we have not been able to find any definite correlation—positive or negative—between regional variations in the seasonal schedule of the flowerings of the planktonic flora as a whole or their productivity, and the regional variations in the temperature of the surface waters, although such a correlation undoubtedly exists between seasonal variations in the temperature and the succession of dominant species.

Particularly interesting in this connection, is the fact that in 1934 diatoms continued at a low level of abundance throughout April in the western basin where the concentrations of nutrients had been highest in March; whereas in the eastern basin under essentially the same conditions of temperature and light, April flowering was intense. Nor can the longer

[16] Concentrations of nitrites and ammonia were so low throughout the year 1933–1934 that no attempt has been made to relate phytoplankton to them. For an account of these the reader is referred to Rakestraw (1936) and Redfield and Keys (1938).

lag in diatom production in the first of these localities be laid to the score of insufficient "seeding," since the species responsible for the vernal flowerings elsewhere, were also present there at the time.

Summation of available evidence thus leads to the conclusion that in the Gulf, as in sundry other localities (Gran, 1932, p. 351; Gran and Braarud, 1935), something more than a mere adequacy of nutrients—and something less obvious than any particular temperature or degree of illumination—is needed before the vernal outburst of diatoms can take place.

Vertical Stability of the Water Column. Gran and Braarud (1935) have already shown that although active turbulence of the water favors the production of planktonic plants in shoal regions such as George's Bank, it may also prevent the development of rich flowerings if the turbulent layer through which the vegetable product of the illuminated zone is dispersed downward, be of any considerable thickness. It is on this basis, and with a high degree of probability, that they explain the rather poor production of phytoplankton in the Bay of Fundy, in the face of the rich supply of nutrients that prevails there throughout the spring and summer. The data for 1933–1934 now afford an opportunity to test the efficacy of turbulence prior to the vernal stabilization of the water, as a limiting factor for the open Gulf.

The most hopeful line of attack on the problem is to follow the coincident changes in floral abundance and in the degree of stabilization, at the localities where records were obtained both before, during and after the vernal outburst. In the table herewith, stability is stated as the difference in density [17] between the surface and the 30 meter level.

The localities, representative of the major subdivisions of the Gulf, fall into several categories. The simplest situation is that existing on George's Bank where, corroborating Gran's (1933) and Braarud's (1934) summer data, flowerings of at least moderate richness (up to 142,000,000 per column) can develop in spring, when the water column has no measurable stability, but where the total depth of water (20–80 meters) does not greatly exceed that of the zone of production. A rich flowering was similarly recorded in 1925 in the shoal waters of Cape Cod Bay (maximum depth, 53 meters) in December when the water had either no stability, or even a negative stability.

The situation is equally clear-cut, but antithetical, at the sampling location off Mt. Desert Island where the vernal outburst did not occur until the upper 30 meters had become stabilized, following a period (no data for January) during which the waters had a low stability. And the situation in regard to nutrients suggests that this order of events applies equally to the southern part of the western basin, where the cruises missed the vernal flowering but where the very low values of 17 mgs. of phosphate and 4 mgs. of nitrate early in May (Figs. 5, 7) fix this as having occurred shortly previous, i.e. when the difference in density between the surface and 30 meters was at least 0.2; whereas in March, January and December it had been only 0.01, 0.04 and 0.01, respectively. In other cases, however, in which the sequence is basically similar the preflowering period of instability is less protracted, being confined either to March, as in the coastwise area near Seguin Island and in the southeast part of the basin, or to January, as in the eastern side of the Gulf near Lurcher Shoal and in deep water in the northwestern part, to judge from the situation as regards nitrates and phosphates.

[17] Density = 1000 (specific gravity − 1).

Locality	Month	Stability	Phytoplankton Cells per Column
Eastern George's Bank	Dec.	—	4080
	Jan.	0.02	2618
	March	0.02	44,110,000
	Early May	0.03	9,000,000 (av.)
	Late May	0.00	1,520,000 and 142,000,000
Western George's Bank	Dec.	—	—
	Jan.	0.00	18,084,000
	March	0.00	27,860,000
	April	—	—
	Late May	0.01	15,360,000
South Eastern Basin	Jan.	0.22	1,859,000
	Mar.	0.01	550,000
	Early May	0.09	2,121,850,000
North Channel	March	0.10	26,730,000
	Early May	0.01	489,850,000
Western Basin, North	Dec.	0.12	1,620,000
	Jan.	0.04	4,675,000
	March	0.02	3,245,000
	April	0.17	1,260,000
	Late May	—	730,000
Western Basin, South	Dec.	0.01?	570,000
	Jan.	0.04	3,498,000
	Mar.	0.01	853,000
	April	0.23	80,000
	Late May	—	9,000,000
Near Cape Cod	Dec.	—	3,120,000
	Jan.	0.05	7,216,000
	Mar.	0.15	14,493,000
	Early May	0.30	8,840
Lurcher Shoal	Dec.	0.10	3,230,000
	Jan.	0.04	1,672,000
	March	0.15	25,630,000
	April	0.19	2,750,750,000
Off Portland	March	0.03	60,655,000
	April	2.91	447,090,000
Off Seguin Island	Dec.	0.42	80,000
	Jan.	0.59	5,269,000
	Mar.	0.13	117,425,000
	Apr.	0.90	5,056,550,000
Near Mount Desert Island	Dec.	0.36	550,000
	Mar.	0.03	2,805,000
	Apr.	0.22	3,238,850,000

Thus it appears that rich flowerings did not develop in certain sections of the Gulf, mainly in the bowl, in the spring in question until a positive stability of approximately 0.1 had built up in the upper 30 meters. Lack of stability of the water column with consequent turbulence may then perhaps be classed as one of the factors which, in conjunction, are responsible for the very considerable lag between the date when the water is fully restocked with nutrients and that when the vernal outburst of vegetation occurs. However, it is not possible to explain on this basis the situation existing in the northern coastal zone as illustrated by the station near Seguin Island (see preceding table) where the water was decidedly stable throughout the period from December to April, but where the lag was as long and the contrast between autumn-winter poverty and vernal richness of vegetation as sharp as it is anywhere in the Gulf. Neither does the state of stability of the water offer any explanation for the failure of productive flowerings to develop in the coastal belt in the Nova Scotian side of the Gulf (e.g., near Lurcher Shoal), in the deep water in the northwestern part, on the eastern part of George's Bank in December, or in the southeastern part of the basin in January, for the water had about the same stability at those localities (or lack of it in the case of George's Bank) in those months and with an abundance of nutrients as it had at the time of the spring flowerings.

We can only conclude then, that while under certain conditions a lack of stability may operate to prevent active flowerings in the deep parts of the Gulf generally during the winter months, this is only part of the story, and that some other coincident factor acts in the same direction, though clearly not with universal efficiency—witness the December flowering recorded above (p. 155) for Cape Cod Bay. This factor, we suspect, is to be sought in the effects on the flora of grazing by herbivorous members of the animal plankton, the importance of which has been stressed of late, especially by Harvey (1934a).[18]

Effects of Grazing

Unfortunately we are in no better position than were Gran and Braarud (1935, p. 422) to estimate the effect of grazing. Earlier surveys (Bigelow, 1914a, 1926) point, however, to an autumnal increase in zooplankton in the Gulf so pronounced that vertical hauls yielded on the average more than twice as much in the Massachusetts Bay region in October of 1915 as in the preceding August (Bigelow, 1926, p. 87). The planktonic population of animals then decreases through late autumn and early winter, to reach its minimum over the Gulf generally, by the last part of February or first days of March. The Gulf of Maine thus falls in the category of localities where the vernal maximum for planktonic plants shortly succeeds the yearly minimum for planktonic animals—a relationship the significance of which is emphasized by Fleming (1939); and the evidence of a causal relationship between the mutual fluctuations of the two groups is as strong as could be expected without precise numerical information as to the abundance of herbivores and their consumption rate.

Termination of the Vernal Outburst

Phosphates and Nitrates. Gran and Braarud (1935) have concluded that the chief factor limiting the production of phytoplankton in the open Gulf during the summer, i.e. after the climax of vernal production, is the low content in nutrient substances of the surface

[18] For a recent discussion of this subject, with calculations of its importance as a determinant of plant abundance, see Fleming, 1939.

layers that results from the draft made on them by the planktonic plants, coupled with the hindrance to their renewal from below that results from the aestival stratification of the water column. They have further pointed out that "where the stratification is broken as on George's Bank, and near the coast a richer production is possible also during the summer"

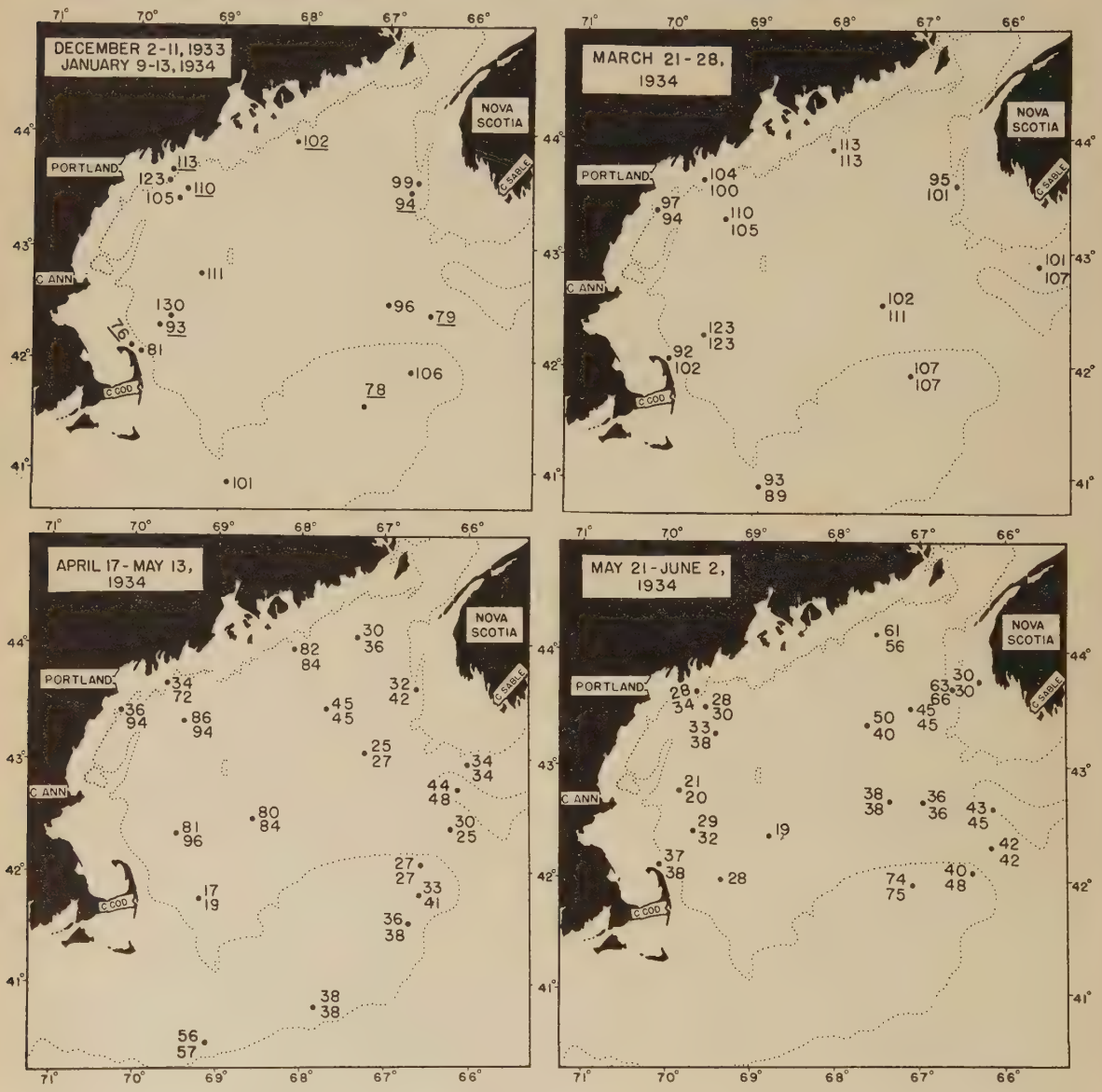

FIG. 5. Milligrams of PO_4 per cubic meter, at 10 meters for December (underlined) and January; and at the surface (above) and ten meters (below), or surface alone, for the other months.

(Gran and Braarud, 1935, p. 403). They also concluded that in the particular year (1932) when their studies were carried out, phosphates were more important than nitrates as a limiting factor. In 1933–1934, however, the relative importance of these two classes of compounds was clearly the reverse in influencing vegetable production.

The vernal outburst of diatoms results, it is true, in a very considerable reduction of phosphates in the upper water strata (Redfield, Smith and Ketchum, 1937) as appears from a comparison of the values for December, January and March with those for April and May (Fig. 5). This indeed was to be expected. Neither is there anything astonishing in the fact that it was in the eastern side of the Gulf where the production of plant cells was the most active from March through April (p. 157) that the coincident reduction in phosphates was the most severe, i.e. from an average of about 107 mgs. of phosphates (PO_4) at 10 meters in March to 42 mgs. per cubic meter in April. Gran and Braarud (1935, p. 395) have, in fact, shown that a much more severe impoverishment may ensue locally, having recorded two instances of total exhaustion of phosphates in the upper 10 meters off Casco Bay and off Mt. Desert Island in May, with coincident values as low as 3–14 mgs. (PO_4) [19] per cubic meter at neighboring stations; 4–15 mgs. in the same general region in June; and 9–45 mgs. in August of 1932.

On the other hand, the late May chart for 1934 (Fig. 5) shows that in that particular year very considerable quantities of phosphates (average 40 mgs.; maximum, 75 mgs.) still persisted in the upper stratum after the eclipse of the major outburst of vernal vegetation with no evidence that even the most active centers of production had resulted in a reduction of phosphates below 20 mgs. per cubic meter at 10 meters, or below 21 mgs. at the

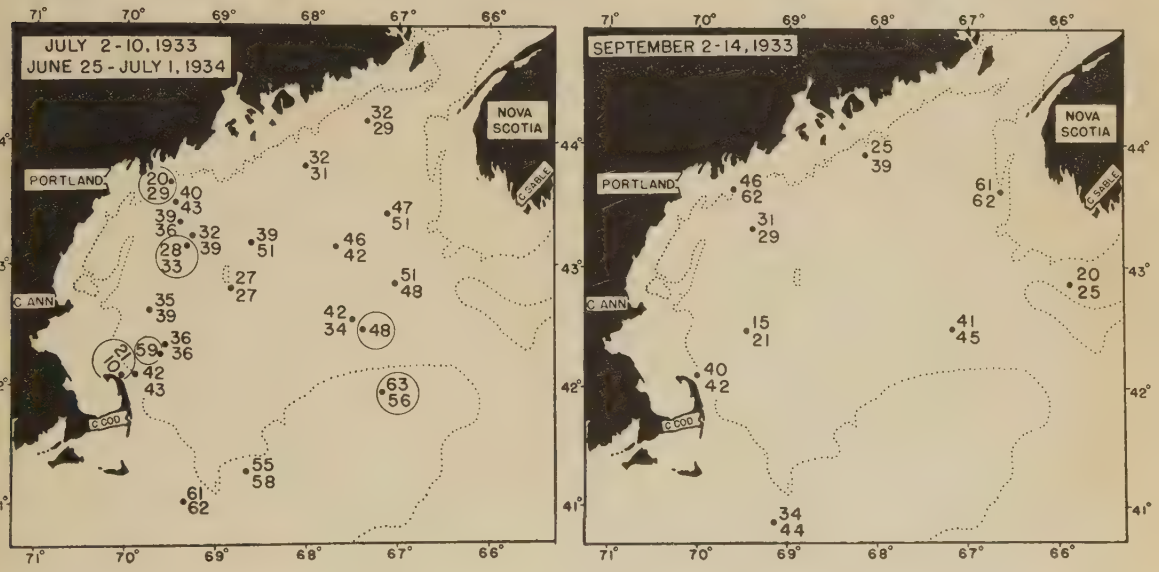

Fig. 6. Milligrams of PO_4 per cubic meter at the surface (above) and 10 meters (below). Values for June–July 1934 encircled.

surface over any considerable subdivision of the Gulf. The charts for the summer and autumn (Fig. 6) reveal one case where the phosphate value fell as low as 20 mgs. at the surface, averages at 10 meters being 29 mgs. for June, 39 mgs. for July, and 36 mgs. for September, even if the richer supply on George's Bank be left out of account. And we may say at once that in 1934 the concentration of nitrates during the season when it was scarcest

[19] For comparative purposes, all phosphate values published by other authors are stated here as PO_4.

was very seldom as much as 10 mgs. less at the surface than at 10 meters, which is well above the compensation depth for phytoplankton during the vernal-aestival half year (Gran and Braarud, 1935, p. 403). Rakestraw (1933) also found 13–34 mgs. at 10 meters at 8 out of 9 stations in the basin of the Gulf and on George's Bank in early August of 1932, with reduction to 8 mgs. at one station only.

Data for the two years combined thus indicate that although the growth of phytoplankton may result in extreme impoverishment of phosphates locally and temporarily, both in spring and in summer, it is more usual for phosphate values to continue higher than about 20–30 mgs., over the Gulf generally, throughout the vernal half year even at the stations where the greatest production of planktonic plants takes place. We are thus faced with the question whether or not a concentration of phosphate as great as about 20–30 mgs. per cubic meter is likely to be less than sufficient to support a (numerically) strong population of planktonic plants of one species or another: in other words, of what importance as a causative factor is a reduction in phosphate of that amount likely to be in relation to the very severe impoverishment in planktonic vegetation that takes place over so much of the Gulf between April and the last of May (p. 161). To attempt a categorical answer would of course be premature, pending some definite knowledge of the nutritive requirements of the particular genera of plants concerned, mainly Thalassiosira and Chaetoceros.[20] It is, however, suggestive that the zone of production was nearly as rich in PO_4 in the Gulf, at its poorest, as it is at its richest in the English Channel, where reported values range between 40 and 75 mgs. per cubic meter just prior to the vernal outburst of vegetation (Atkins, 1925–1929; Harvey, 1928a; Cooper, 1933, 1933a, 1938; Harvey, Cooper, Lebour, and Russell, 1935).

Near Møre, also, on the west coast of Norway the highest phosphate value reported at 10 meters by Braarud and Klem (1931) was 67 mgs., the average 42 mgs., while the maximum at 25 meters was only 69 mgs. at any time of year. Similarly, Marshall and Orr (1926) had between 53 and 67 mgs. only, in March at 10 meters, and about 53 mgs. in February at one locality, with about 53 mgs. at a second, in the Clyde Sea area (west coast of Scotland), preceding the April outburst of diatoms, with July values at 10 meters (preceding the August flowering) of 40–47 mgs. and 53–60 mgs. respectively, at these two localities.

Phosphate concentrations of 40–75 mgs. PO_4 per cubic meter being thus proved sufficient to support intense flowerings of diatoms in seas comparable in depth, temperature and salinity, there is no apparent reason, so far as phosphates are concerned, why the bowl of the Gulf of Maine should not have supported a much richer flora from May onward through the summer of 1934, than was actually the case. This is in line with Gran and Braarud's (1935) conclusion that phosphates are seldom—if ever—a limiting factor in the inner part of the Bay of Fundy, where most of the values for the 10 meter level for May, June and August of 1932 fell between 13 and 50 mgs. This, according to Davidson (1934, p. 43), applies equally to the Passamoquoddy region where the minimal phosphate values recorded for the period August 1930–October 1931 were 36 mgs. within the Bay, and 24 mgs. off its mouth.

In short, it is doubtful whether the growth of phytoplankton was seriously limited over any extensive subdivisions of the Gulf at any season by any widespread scarcity of phos-

[20] For a discussion of the nutritive requirements of *Nitzschia Closterium*, see Ketchum, 1939, 1939a.

phates in 1933–1934. But we have no basis for judging whether the low values recorded locally in the open Gulf in 1932 by Gran (1933) and by Gran and Braarud (1935), contrasted with those for 1934, represented an annual difference involving the Gulf as a whole, or whether centers of equally severe impoverishment for phosphates may have developed here and there in 1934 also, but were missed by the grid of stations. This latter supposition seems, however, the more likely of the two, i.e., that even though phosphates be usually in sufficient amount over the Gulf as a whole, they may be so exhausted by flowerings of great intensity in particular localities where vertical circulation is weak, as to become a severely limiting factor locally, and for a time.

The vernal outbursts of 1934 reduced the average concentration of nitrates at the 10 meter level from 133 mgs. per cubic meter in March to 44 mgs. in late April–early May, to 18 mgs. by late May to early June (Fig. 7), and to 8 mgs by the last days of the latter month, when two cases of total exhaustion were recorded for the 10 meter level (Fig. 7), and three for the surface. Although the more comprehensive July survey for 1933 (Fig. 8) failed to reveal any values lower than 9 mgs. at 10 meters or lower than 8 mgs. at the surface, the general mean at 10 meters for that month was only 14 mgs., and the maximum only 20 mgs. The combined record thus makes it clear that in the open Gulf of Maine pelagic plants made a much more severe draft on the supply of nitrates within the photosynthetic zone during their vernal multiplication than they did on the phosphates—a draft that finally resulted in total exhaustion of the salt in question over certain areas, especially in the basin of the Gulf—something that has rarely been recorded for phosphates. In this respect, as Gran and Braarud (1935) have already emphasized, the Bay of Fundy contrasts strongly with the open Gulf, for while plant growth considerably reduces the richness of the surface stratum in nitrates in the Bay as well, below the probable February–March value of more than 100 mgs., the impoverishment is not as extreme as in the open gulf, the minimum value recorded in their tables being 19 mgs. even at the surface, with average surface values of 43 mgs. for May–June (5 stations); 41 mgs. for August, and 31 mgs. for September (3 stations). At the same time considerable evidence has accumulated to the effect that rich flowerings of planktonic plants demand on the whole a richer supply of nitrates than of phosphates, for we have found no case recorded where an active vernal outburst of diatoms is not preceded by a nitrate concentration of at least 40–50 mgs. per cubic meter at some level within the photosynthetic zone. In the English Channel, for example, Harvey (1928a) found 60–80 mgs. at the surface in February and March. Braarud and Klem (1931) had upwards of 40 mgs. in March of 1929 and 1930 in 12 out of 14 determinations at 10 meters and at the surface (average more than 63 mgs., maximum more than 128 mgs.), in Norwegian waters near Møre, with 30 and 53 mgs., respectively, at 25 meters in two other cases, when the 10 meter values were low (14 mgs. and 6 mgs.). Gessner (1933) reports surface values averaging 92 mgs. at 11 stations along a profile crossing the Baltic on February 19, of 1933, i.e., before diatoms began to propagate actively. And Moberg's (1928) graph showing somewhat more than 50 mgs. per cubic meter off La Jolla, California at the 30 meter level where diatoms were the most abundant, but with the surface deficient in both nitrates and diatoms in measurable amount, is of similar import.

In most other localities where the nitrates have been measured at a date shortly preceding rich outbursts of vegetation, the concentrations found have been even higher; in the Barents Sea, for example (Kreps and Verjbinska, 1930); in Puget Sound (Phifer and Thomp-

son, 1937); and proverbially so in the Antarctic (Ruud, 1930). On the other hand, what few determinations have been made, in parts of the ocean where there are no characteristic peaks of abundance for phytoplankton, have shown very low values for nitrate in the illuminated zone. Cases in point, using modern methods, for the open oceans are found in

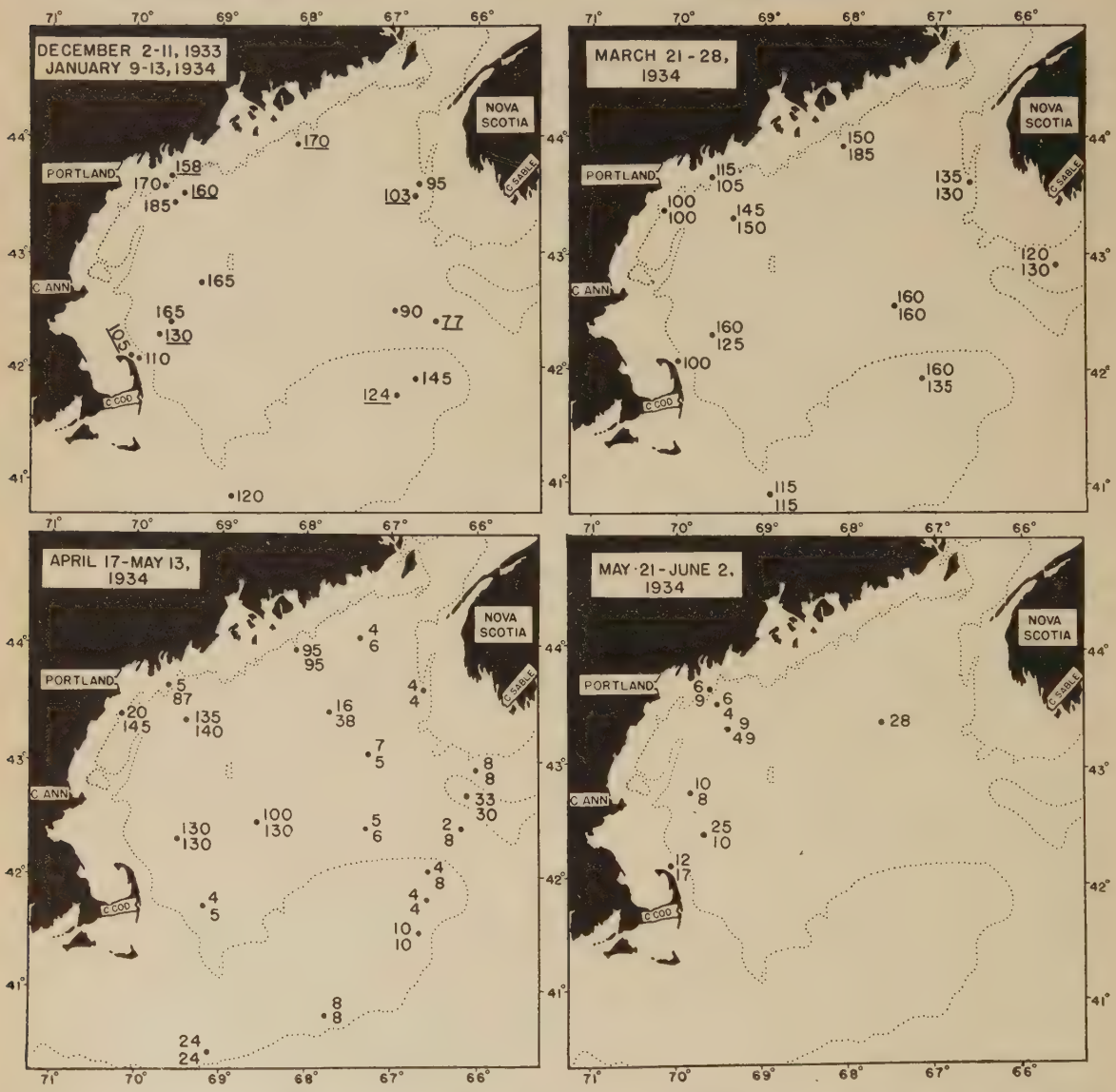

Fig. 7. Milligrams of nitrate per cubic meter at 10 meters for December (underlined) and January; and at the surface (above) and 10 meters (below), or surface alone, for the other months.

the South Atlantic (20 mgs., Ruud, 1930), off the coast of Portugal (11–15 mgs., Harvey, 1928a), and in the Caribbean and Sargasso Seas (Rakestraw and Smith, 1937).

A reduction of the nitrate concentration below 20–30 mgs. per cubic meter in the illuminated zone such as follows the vernal outburst of diatoms over the Gulf of Maine generally, might therefore be expected to act as a definitely limiting factor for plant growth

—at least for diatoms—and still more so the total exhaustion that involved such considerable areas in the early summer of 1934 (Fig. 7).

Without attempting to proceed more deeply into the matter (available information is not sufficiently detailed) the evidence is strong that impoverishment of nitrates, which contrast in this with phosphates, by consumption during the vernal outburst of diatoms,

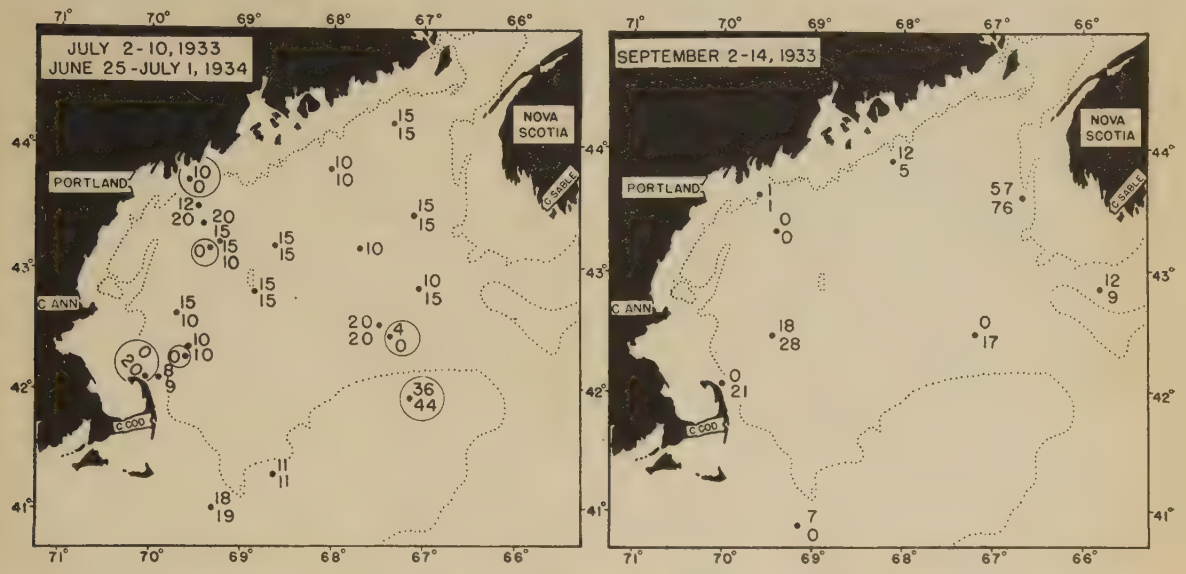

Fig. 8. Milligrams of nitrate per cubic meter at the surface (above) and at 10 meters (below). Values for June–July 1934 encircled.

was the chief cause for the subsequent decline in abundance of planktonic plants over the Gulf as a whole in the particular year in question. We incline also to the belief that while there may be a considerable variation from year to year in this respect, the reduction of nitrates is more likely to be the limiting factor of the two on the whole in the Gulf, during the season when renewal from greater depths is severely limited by the strongly stratified state of the water, because the nitrates from decomposing organic matter are returned more slowly to the water than are the phosphates, there being a greater number of intermediate steps in the process (Cooper, 1937, 1937a).

In the inner parts of the Bay of Fundy on the other hand Gran and Braarud (1935, p 430) have shown that the limiting factor is not the supply of nutrients of any sort since nitrates like phosphates are in sufficiency there right through the season, but the extraordinary turbidity which limits the penetration of light, thereby reducing the thickness of the zone of production, combined with great turbulence that rapidly disperses the vegetable products of that zone downward through the entire water column (p. 169).

The effects of grazing must as certainly be taken into account, in connection with the impoverishment of the flora, following the vernal climax (when such occurs) as it is in connection with the situation existing in winter. Again, we can make no estimate of this effect beyond noting that in April, when the phytoplankton was locally so abundant that many of the amoeboid and ciliate protozoa were found literally packed with the cells of Thalassiosira.

Regional Variations in Plant Production in Summer

It has long been appreciated that in regions where the transparency of the water is normal, active turbulence tends to favor the production of phytoplankton by constantly bringing up fresh supplies of nutrients from the deeper layers. And it is on this basis that Gran and Braarud (1935) have explained the fact that a rich production of diatoms continues into the summer in the coastal belt eastward from Penobscot Bay as well as on George's Bank. Actually, however, the concentration of nitrate recorded by them in August of 1932 was somewhat lower at the surface close to Mt. Desert Island (32 mgs.) than it was over the basin to the southwest (43 and 48 mgs.) where the flora was much less rich (Gran and Braarud, 1935, Fig. 40). Neither is the evidence clear in this respect for George's Bank, since the stock of nitrates was about the same in the basin of the Gulf, where the phytoplankton was scarce, as on the eastern part of George's Bank, where it was fairly plentiful at the time of the August 1932 and July 1933 cruises; while in June–July of 1934, when the phytoplankton was about as abundant on the northeast part of George's Bank as it was in the neighboring parts of the basin to the north, nitrates were considerably richer in the one locality than in the other (Fig. 8).

The data are not sufficiently detailed as to date or as to location to show how generally the expected correlations between plant abundance and the supply of nutrients applies at times and places where flowerings of diatoms take place late in the summer or early in the autumn. However, Rakestraw's (1933) report of 20–27 mgs. of nitrate at 10 meters in the basin, and on George's Bank as well, early in August of 1932, with Gran and Braarud's (1935) of 32–48 mgs. at 10 meters and at the surface on the northern side of the gulf in that same month, with one value as high as 76 mgs. at 10 meters in September of 1934 (Fig. 8) suggests that in mid- and late summer there is a prevailing tendency for nitrates to be supplied to the photosynthetic zone from below faster than plants consume them.

It is also suggestive in this connection that the concentration of nitrate was considerably higher at a station near Lurcher Shoal on the Nova Scotian side of the Gulf at the time of the September cruise of 1933 than anywhere in the basin to the westward or on George's Bank (Fig. 8), but with no significant difference to correspond in the number of plant cells. The obvious inference is that the late summer diatom maximum which develops along the northern coastal belt and over the southern banks of the Gulf as well, affects the nutrient supply not only in these particular regions but over the bowl as a whole. On the contrary the coincident presence of such a considerable quantity of nitrates in the surface waters of the eastern side of the Gulf is a reason for doubting whether the second flowering extended to the coastal waters off Nova Scotia at all in the year in question; whether, in fact, it is a regular item in the seasonal cycle there (p. 164).

Autumnal Impoverishment

The records for September 1933 show that the second flowering of late summer or early autumn may again reduce the nitrates to the vanishing point here and there; witness the two instances of total exhaustion indicated on Fig. 8, and a third where 1 mg. only was recorded at the 10 meter level, with only 5 and 9 mgs. at two other stations. Phosphates also had been reduced to 21 mgs. at one station in that month, to 25 mgs. at another. Without data for October we have no way of knowing how soon this tendency toward depletion becomes more than nullified by an increasing supply from below, consequent on

the decreasing stability of the water column—certainly this happens before the end of the autumn as proved by the high concentrations of nutrients at the 10 meter level in December (Figs. 5, 7). However, the instances just stated are enough to show that nitrates (perhaps phosphates) may as sharply limit the plant outbursts of early autumn as they do those of the spring (p. 178). At the same time, it is probable that the draft made upon the flora by the planktonic animals that feed upon it increases in severity during mid-autumn, for available data suggest that a diminution in the volume of zooplankton during the summer is "followed by an autumnal increase, which was so considerable in 1915 that there was over twice as much plankton per square meter in water only 80 meters deep by the end of October," in the Massachusetts Bay region as at a neighboring locality in 140 meters in August, with evidence that this augmentation was general throughout the western coastal belt at least (Bigelow, 1926, p. 87, 88). Increasing activity of vertical turbulence may also act adversely in some localities as early as October, for the difference in density between the surface and the 30 meter level was only about 0.07 in October of 1933 in the northwestern part of the basin, where it had been about 2.37 in the previous month and about 1.62 in July, but it is not likely that the break-down of stratification becomes generally effective as a limiting factor until mid-winter (for further discussion of this factor, see p. 169).

Summary

The phytoplankton of the Gulf is scanty (the familiar winter minimum) from late autumn until early spring. In the one year of record the minimum was reached in December in the western coastal belt, and thence southward across the southern rim of the Gulf, but not until January in its eastern side generally. The counts for 1933–1934 point to some 80,000 cells per column as about the minimum, some 18 million per column about the maximum, and about 4 million per column about the average to be expected for December and January combined in a normal winter (Fig. 2). Local flowerings have however been encountered in the Massachusetts Bay region in December (p. 155), and on the western part of George's Bank in January.

In most years the numbers of vegetable cells (diatoms chiefly responsible) increase considerably in the western coastal belt and on western George's Bank on the one hand, and in the region of Passamoquoddy Bay on the other, by mid- or late March, even by late February in an early spring, with the vicinity of Cape Elizabeth as the site of the earliest flowering. In some years flowerings may develop equally early in the shoal waters on the eastern side of the Gulf, south from Nova Scotia, and over the eastern part of George's Bank, but not until a month or so later in other years, nor until April or even May—according to locality— in the northern coastal belt or over the bowl of the Gulf generally. This regional contrast is illustrated by the charts for March and April (Fig. 2).

In all parts of the Gulf yet studied the vernal augmentation soon results in an increase in the number of cells—chiefly diatoms— so great that by the time the outburst reaches its climax, the number in the water averages at least a thousand times as great as it is in late winter for the Gulf as a whole; in fact multiplication by 63,207-fold has been recorded locally.

The vernal increase in the number of cells per column, after continuing rapid for a period varying locally in duration from a few days to several weeks, then either abruptly ceases, or at least equally abruptly declines in its rate, a stage in the seasonal cycle indicated on graphs of time-abundance distribution by a sudden change in the slope of the curve

(e.g., as in Pt. II, Fig. 6 of this report, Lillick, 1940). This point is named here the "vernal climax," rather than by the more usual designation "vernal peak" as more correctly descriptive of events in regions where high levels of abundance persist for considerable periods.

The vernal climax is reached in the region of Massachusetts Bay by early or mid-April (depending on the year), and equally early on the eastern side of the Gulf generally, including the eastern parts of George's Bank; a week or two later (late April) in the southern part of the western branch of the deep basin; shortly thereafter (late April–early May) in the northern extension of the latter and in the northern coastal belt; latest of all (May or June) in the Bay of Fundy region. The wide variation in this respect recorded from year to year for Passamoquoddy Bay suggests that the climax may equally be expected to occur as much as three weeks earlier in an early spring than in a late, in most parts of the Gulf as well.

The maximum number of cells recorded has ranged from about 2 billion to about 14 billion per column (Fig. 2), in the parts of the open gulf where counts have been made at or near the vernal climax, in Passamoquoddy Bay and in the lower part of the Bay of Fundy. On this basis no one major subdivision of the Gulf for which information is available can be classed as significantly more productive of phytoplankton than another at the climax season. Nor have we any positive reason to assume any great difference in either direction for George's Bank or for the northern part of the Western Basin, but the inner parts of the Bay of Fundy support a much less abundant flora according to Gran and Braarud's (1935) observations.

Available information for the several years combined shows that the Gulf falls into two subdivisions as regards the phytoplanktonic cycle subsequent to the date at which the vernal climax is reached. In the one, restricted to the northern coastal belt and to the Bay of Fundy region, a rich flora may persist through June or even into July. By present indications George's Bank also falls in this category. In the other subdivision, which includes all other parts of the Gulf, the vernal climax is succeeded by an abrupt impoverishment, most severe in the open bowl outside the 200-meter contour line and from Nova Scotia out across the Eastern Channel where counts were lower in late May (Fig. 2) than at any other season. The regional contrast between areas rich and barren is also widest in the late spring, when it may be of the order of 174,570 to 1.

A moderate increase in the number of vegetable cells takes place over the bowl generally from July through August following the late spring impoverishment, with more productive flowerings in late summer in the northern coastal belt, in the Bay of Fundy region and on George's Bank; also in September in the Massachusetts Bay region and southward. Whether or not this second flowering results in a definite peak of abundance in any particular region depends on the degree to which aestival impoverishment may have preceded it there.

The second flowering is followed by progressive autumnal impoverishment, the date when this commences depending on the date when the second flowering occurs, which varies regionally and from year to year as described on page 163. Further depletion through later autumn leads directly to the early winter state outlined above, there being no reason to suppose that active flowerings ever develop even locally in October or in November.

Extreme and mean numbers of cells per column for 1933–1934 were as follows:

PHYTOPLANKTON

Month	Mean	Maximum	Minimum	No. of Stas.	Ratio Maximum to Minimum
December 1933	1,852,000	3,230,000	80,000	8	40.4 : 1
January 1934	6,026,000	12,073,000	1,672,000	10	7 : 1
March 1934	29,487,000	117,425,000	550,000	11	213.5 : 1
April–May 1934	1,759,767,000	13,965,600,000	80,000	46	174570 : 1
May–June 1934	55,347,000	142,100,000	50,000	46	2842 : 1
June 1934	6,650,000	27,310,000	1,120,000	6	24 : 1
June–July 1933	21,685,000	198,080,000	800,000	16	247.6 : 1
September 1933	37,660,000	283,012,000	2,013,000	11	140 : 1
October 1933	7,856,000	18,161,000	649,000	6	28 : 1

The deeper strata of the Gulf below about 80 meters are rich in phosphates (> 100 mgs. per cubic meter) and in nitrates (> 200 mgs. per cubic meter) throughout the year, and values equally high characterize the entire water column up to the surface from December through March. Vernal flowerings do not develop, however, on any large scale until at least 3 months after the stock of phosphates and nitrates has been fully replenished in the photosynthetic zone. Except in special situations such as the turbid waters of the Bay of Fundy, light is also sufficiently intense at the latitudes in question for active photosynthesis throughout the winter, as proved by the occurrence of local flowerings in Cape Cod Bay in December (p. 155). Neither does available evidence suggest that the initiation of general vernal flowerings is dependent on the nutrient increment (of whatever substances) contributed by river freshets, or on the attainment of any particular value of temperature, but that the generally stimulating factor is the attainment of at least a slight degree of stabilization of the water column.

In the year 1934 the vernal outburst of planktonic vegetation reduced the concentration of nitrates in the productive zone to such a degree as to make it probable that the flowerings were largely self-limited in this way. In some years—as in 1932—phosphates also are locally reduced below the minimum requisite for active growth of diatoms. This, however, did not happen in 1934. Thus, by present indications, nitrates are much more likely to act as a generally limiting factor in vernal production than are phosphates. In the Bay of Fundy, however, Gran and Braarud (1935) have maintained that the chief limiting factor is the great turbidity of the water, combined with its turbulence. Available data do not allow quantitative estimates of the effects of grazing by herbivorous members of the zooplankton at this season.

It appears that from midsummer on, the concentration of nitrates tends to increase in the illuminated zone, providing the bases for the second flowerings, but the data are not sufficiently detailed for more than very general statement in this respect. The records for September show local self-limitation of the second flowerings, as of the vernal, by exhaustion of the supply of nitrates (not, however, of phosphates); and it is probable that the effect of grazing is also a major factor in autumnal impoverishment of the phytoplankton.

Numerical Distribution of Planktonic Protozoa in the Upper 80 Meters of Water

The data for 1933–1934 provide for the first time a picture of the numerical distribution of planktonic protozoa for the Gulf of Maine as a whole at different seasons of the year; previous information regarding this group was confined to a brief discussion by Bigelow (1926), and to counts of zooflagellates and ciliates included under the general heading "Phytoplankton" by Braarud (1934) for the offshore waters in summer, and by Gran and Braarud (1935) for the Bay of Fundy region. We should, however, emphasize that although the counts per column given in the preceding chapter for the planktonic plants include practically the total stock of the latter because of their limitation to the illuminated zone, this does not necessarily apply to the protozoa which, on occasion, may have been present in significant numbers below 80 meters [21] in the deeper parts of the gulf, as they certainly were at several of the Fundian stations (Gran and Braarud, 1935, tables). Hence the counts are minimal; complete enumeration for the entire water column, surface to bottom, would be larger by an unknown amount.

The collections of 1933–1934 include Heliozoa, Radiolaria, Foraminiferae, Ciliatae, Zoomastigodae, a few members of the Sarcodina (mainly Amoebae), which were moderately abundant in the spring, and others not identified, with the Ciliatae forming the larger part. The genera most commonly represented are Strombidium, Mesodinium, Parafavella, Tintinnus, Tintinnopsis, Stenosemella, and Laboea. Gran (1933), Braarud (1934) and Gran and Braarud (1935) also give counts of various other ciliates. Foraminiferae were extremely rare, not more than a dozen individuals having been detected in the entire survey; and Radiolaria were not found at all in the year 1933–1934, although Acanthometron was abundant near Cape Ann and in the western basin in August 1914, comparatively plentiful at scattered localities in September 1915, and occasional west and south of Nova Scotia in April 1920 (Bigelow, 1926, p. 460). Few zooflagellates, other than Zoomastigodae, were observed by us. Bodo is, however, recorded in great numbers at two stations in the open Gulf for July 1933 by Braarud (1934), hence it is probable that these delicate and easily destroyed forms were generally abundant as Lackey (1936) found them near Woods Hole, but that they had either distintegrated before the collections of 1933–1934 were examined, or were damaged beyond recognition by the methods used.

The protozoa have not been identified as to species; taxonomic discussion of the group is therefore omitted here. For such in the Bay of Fundy, see Gran and Braarud (1935).

The protozoan counts presented on Figs. 9–10 are summed up in the following table.

Month	Year	Mean	Maximum	Minimum	No. of Station
December	1933	435,000	950,000	90,000	8
January	1934	291,000	891,000	0	10
March	1934	1,405,000	10,780,000	0	11
April–May	1934	630,000	1,380,000	20,000	10
Late May	1934	320,000	56,000	50,000	6
June	1934	470,000	2,000,000	0	6
June–July	1934	1,208,000	3,920,000	0	16
September	1933	489,000	1,595,000	0	11
October	1933	474,000	1,265,000	55,000	6

[21] The deepest sampling level for the cruises of 1933–1934.

If the seasonal succession as it occurred in 1933–1934 be representative, the protozoa are at their minimum in the Gulf in January, richest then close to Cape Cod (910,000) and on the eastern part of George's Bank (950,000) (Fig. 9). To illustrate the sharpness of the contrast that may then exist within short distances, we may cite a count of 493,000 off Port-

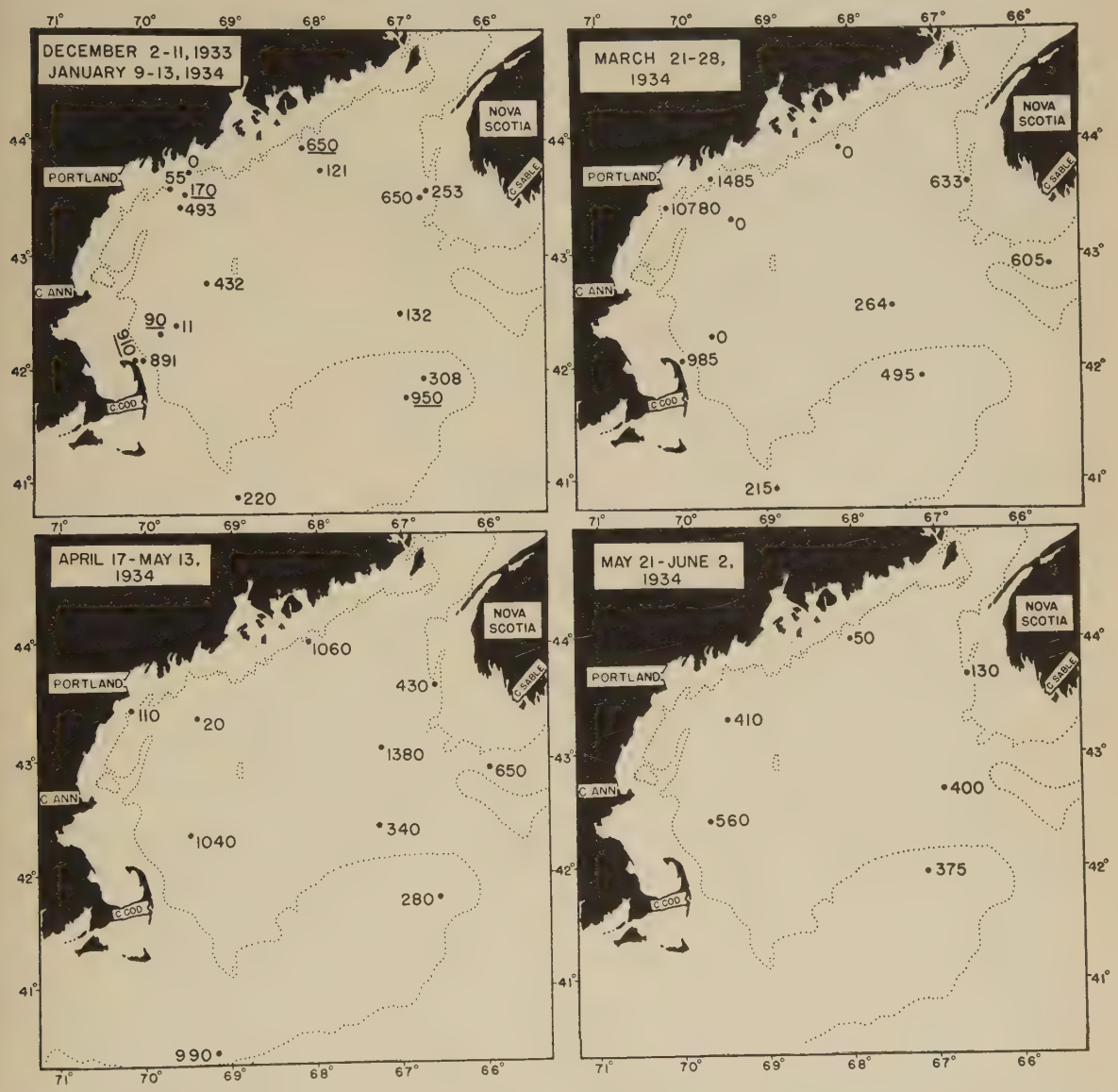

FIG. 9. Numbers of protozoa, of groups sampled (p. 182) in thousands, per 0.1 square meter of sea surface. Values for December underlined.

land, whereas none at all were detected close to the coast near Seguin Island only about 20 miles distant. In the year in question the protozoa had multiplied by March to their yearly maximum (both as to average numbers and as to maxima), when the average was about 4.8 times as great as it had been two months before and the maximum count 12

times greater, though the minimum was the same (0 in each case). These averages are, however, deceptive if taken at face value, for actually the ostensible increase in richness resulted almost entirely from the development of a center of abundance near Portland, where a local swarming of Strombidium raised the March counts (2 stations, average, 6,132,000) to about 22 times as great as those for January (2 stations, average, 275,000), whereas in no other part of the Gulf was the count for either month as much as three times as great as for the other (cf. Figs. 9–10).

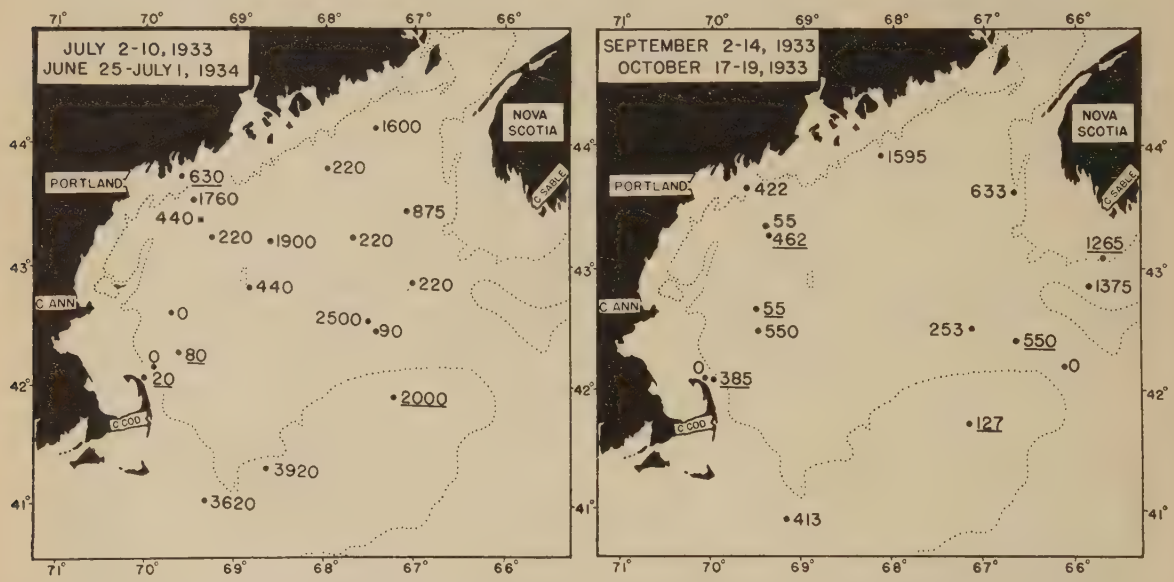

Fig. 10. Numbers of protozoa of groups sampled (p. 182) in thousands per 0.1 square meter of sea surface. Values for June–July, 1934, and October, 1933, underlined.

By late April (Fig. 9) the count for the locality that had been so rich in March had fallen to about 110,000 cells per column, or to about 0.18 of the March value; this was, in fact, the region of greatest paucity at the time of the April–May cruise, when Protozoa were the most abundant at widely separated localities in the southwestern, southeastern, and northeastern parts of the basin (Fig. 9). The correspondence between the late April counts, near the 100-meter line off Mt. Desert Island for 1934 (1,000,000, Fig. 9), and for 1932 (1,210,000) calculated from Gran and Braarud's (1935, table, p. 440) data is very close. However, an April count of 1,630,000 in the northwestern part of the basin for 1932 (Gran and Braarud, 1935) contrasted with 20,000 only at the same general locality in 1934, shows that information in much greater detail will be needed before the significant range of annual variation can be evaluated for this part of the Gulf or for any other.

In the year 1934 vernal enrichment appears to have been confined to rather definitely circumscribed centers, and no great change is indicated in abundance from winter through the early spring on the Nova Scotian side of the Gulf where the recorded counts for March, April and early May varied only between about 0.5 times and 2.5 times as great as those for January (cf. Fig. 9). The average number of protozoa for the Gulf as a whole (320,000) had again declined by the end of May (Fig. 9) to about what it had been in January [22]

[22] Data are lacking for the region of Massachusetts Bay.

(291,000). And the fact that the late May average for the northwestern part of the Gulf was at least of the same order of magnitude in 1932 (about 107,000, 3 stations) as in 1934 (230,000, 2 stations, Fig. 9), makes it likely that general impoverishment at this time of year is a normal stage in the seasonal cycle.

In 1934 an 8-fold increase in the number of protozoa took place on the eastern part of George's Bank at some time between the dates of the late May and late June cruises; also, in the coastal belt near Portland there were about 6 times as many protozoa on June 29 as there had been on April 19 (no data there for May). And while the protozoan population in this last locality was very sparse in late June of 1932 (40,000 from Gran and Braarud's table; no data for that April), the sequence recorded in 1934 appears to have presaged a second and general enrichment in the summer, since the counts for early July of 1933 were more than 3 times as great as those for the spring of 1934, wherever pairs of stations are available for comparison, except near Mt. Desert Island, and twice as great even there (cf. Figs. 9, 10). The average was in fact nearly as great in June–July as for March, the maximum (3,920,000) nearly as great, and the minimum the same (0), while the second richest count for July (3.6 million in the South Channel) ranks considerably above the maximum for any other month except March, so far as the open Gulf is concerned. And the general distribution shown on Fig. 10 as contrasted with Fig. 9 is evidence that the aestival enrichment was much more widespread than the vernal.

Braarud's (1934) counts for two July stations (southeastern part of basin and eastern George's Bank) are especially interesting, not only because they provide the only available evidence as to the abundance of zooflagellates in the open Gulf at any season, but also because they prove that these may outnumber all other protozoa combined in midsummer, for he lists no less than 10,592,000 per column of one genus (Bodo) alone at the one station, and 5,112,000 at the other. But we have no indication as yet whether this represents a generally high level of abundance at that season or whether the two stations in question chanced to sample particularly rich centers for this particular flagellate genus. Acanthometron swarmed off Cape Ann in late August of 1914 (Bigelow, 1917, Fig. 97; 1926, p. 460), but this radiolarian is so large that the numbers concerned were probably not as great as were the July counts for other protozoa (Fig. 10) in 1933. Present indications therefore are that protozoa of all sorts combined usually do not multiply to more than about 30 million per column anywhere in the Gulf during the summer.

Numerical data for the open Gulf for August are confined to counts by Gran (1933) corresponding to between 152,000 and 528,000 per column in the deep basin and 96,000 on the eastern part of George's Bank in 1932, and by Gran and Braarud (1935, Tables) of 160,000 and 296,000 off Seguin Island and off Mt. Desert Island. These suggest about the same general level of abundance in the open Gulf for August as for July; the failure to encounter any very rich centers in August may have been simply a matter of chance. The highest counts for July (Fig. 10) and August are so widely scattered that no one subdivision of the Gulf can be classed as definitely more productive than another at that season—at least on the basis of present evidence. The fact, however, that August counts for the Bay of Fundy in 1932 by Gran and Braarud (1935, Tables) ranged from 1,208,000 to 3,856,000 per column (average 2,314,000) contrasted with a maximum of 528,000 and an average of only 205,000 in the open waters to the southward, is evidence that the summer stock of protozoa is considerably richer within the Bay than it is outside the latter, even though no

center of abundance has yet been encountered in the Bay to rival the July concentration recorded in the southeastern part of the Gulf a year later. It is not likely that this regional contrast between the Bay and the open Gulf is established before mid-summer since counts equalling 1,350,000 protozoa per column in Passamoquoddy Bay and 104,000 in the Bay of Fundy for late April of 1932, 248,000 for the latter a month later, and 80,000, 816,000 and 990,000 (3 stations) for June of 1932 are of the same general range of magnitude as the late April–June counts in one part of the Gulf or another for 1934 (Fig. 9).

In the year 1933 comparatively large numbers of protozoa (1,595,000–1,375,000) were again recorded in the Eastern Channel between Brown's and George's Banks and on the northern side of the Gulf off Mt. Desert Island in September (Fig. 10), in line with which last is an earlier record of abundant radiolarians near Penobscot Bay at the same season (Bigelow, 1926, Fig. 132). Gran and Braarud (1935) also had a very high count at one station within the Bay of Fundy in that month of 1932 (equalling about 2 million per column), with two others in September of 1931, i.e., one of about 7 million within Passamoquoddy Bay, the other of about 1 million off its mouth. Elsewhere, however, the September counts have averaged considerably below those for the preceding two months (whether in the open Gulf or in the Bay); and by October of 1933 (Fig. 10) the numbers per column—mean, maximum and minimum—had fallen to about as low a level as they were in December, though with considerable divergences between individual stations (cf. Figs. 9, 10). The record does not point to any significant change during the early winter—or indeed until the vernal enrichment develops—for although the general average was somewhat larger for December (Table, p. 182) than for January, the maxima were not far apart.

SUMMARY

Planktonic protozoa are at their numerical minimum in the Gulf from mid-autumn through the winter. No widespread important secular fluctuations in abundance are indicated for this part of the year, but the regional variation was wider in January than in any other month, with the most abundant winter population (900,000–1,000,000) in shoal water close to Cape Cod and on the eastern part of George's Bank. In the one year of record a very rich population developed locally in the coastal belt near Portland in March, the result of swarming of one form (Fig. 9). But apart from the two stations directly affected, the average was not greater for March (about 355,000) than for December–January combined (366,000); and the swarm in question was not only confined to a very small area, but did not endure more than 3 weeks, its disappearance leaving the population for the Gulf as a whole not significantly richer in April than during the preceding winter except at isolated stations shown on figure 9. Combination of data for the two years 1933–1934 points, however, to considerable increase in the population from May through June, resulting in counts from 2 to 20 times as high at corresponding stations in early July as in January, with the notable exception of two localities near the tip of Cape Cod, where protozoa appear to have disappeared entirely from the water if zooflagellates be left out of account. Even if these stations be included in the calculation, the June–July average (about 1,208,000) is 4 times that for January, the maximum about 2 times, though the minimum (0) was the same (see Table, p. 182). Two very rich catches of the genus Bodo have also been recorded in July (p. 185).

The counts for 1933–1934 added to various pieces of information for previous years mark mid-summer as the season of maximum for protozoa over the Gulf as a whole, and point to some 4 million per column as approximately the maximum to be expected then. No notably rich counts have been recorded in August; the general level of abundance for protozoa appears, however, to be about the same for that month as for July.

The distribution of the centers of maximum abundance does not point to any one major subdivision of the open gulf—deeper or shoal—as characteristically more productive of protozoa than another at the season of the aestival maximum, but the group averages considerably more abundant in the inner parts of the Bay of Fundy in summer than elsewhere within the region studied.

Locally protozoa may continue abundant into September both in the open Gulf (maximum, 1,595,000) and in the Bay of Fundy (maximum, about 7 million). The general level of abundance averages considerably lower then, however, than in August or July, and by October the counts (both mean and maximum) fall back, roughly, to the December level. Nor have we any grounds for supposing that centers of active production develop anywhere during the late autumn or early winter. The next to the smallest count for protozoa (11,000 per column) was only about 1/8 as great as the smallest for phytoplankton; the largest for protozoa (10,780,000) about 1/1295 as great as the largest for phytoplankton; the grand average for protozoa only about 1/337 that for phytoplankton. These contrasts sufficiently emphasize the paucity of the waters of the Gulf of Maine in unicellular animals as contrasted with unicellular plants.

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Contribution No. 260

CONVECTION AND SOARING OVER THE OPEN SEA[1]

By

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The transfer of momentum between the winds and the sea surface is a fundamental problem of oceanography. In the theoretical treatment of drift currents at sea and of the movements in the turbulent layer of air just above, no consideration seems to have been given to the possibility of a varying pattern of flow under unstable conditions. Recently Langmuir (1938) made measurements of "helical vortices set up by wind" in the surface waters of a lake. Lines of Sargassum weed, which are commonly seen on the central North Atlantic, were mentioned as an indication that similar vortices occur in the ocean. The observations of soaring flight presented below suggest that in unstable air at sea there are definite patterns which vary with the velocity and the stability of the wind.

There is some evidence that the force exerted by the wind on the sea surface cannot be expressed by a single continuous function of wind velocity and other factors, so that the critical values of these factors are also of interest to oceanographers. The soaring gulls seem to provide some clues as to the critical wind speeds at which there are marked changes in the form of convective motion, and thus in the transfer of momentum between the two mediums.

In a recent article on herring gull soaring (Woodcock, 1940), it was pointed out that the flight tactics of the birds vary with the wind and with the relative air and water temperatures. It was also suggested that the variations in flight routine of sea birds might be used to study some of the characteristic air motions over the water. In the present paper further data concerning gull soaring are presented.

The observations used here were made while on board the research vessel "Atlantis." They are confined to a sea area 30 to 600 miles off the east coast of the United States, between the latitudes 16° N. and 45° N. When cumulus clouds were forming, the layer of air in which the soaring was done extended upward from approximately 45 meters above the sea surface ("Atlantis" mainmast height) to the cloud base. Soaring altitudes greater than 620 meters have been measured with a range finder.

All of the air and water temperatures were measured with one

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thermometer; an ordinary laboratory thermometer graduated in whole degrees centigrade. Special care was exercised in making the air temperature measurements, in order to be sure that the thermometer was held to windward of the ship and adequately sheltered from the direct rays of the sun. The heights above the water of the air temperature measurements ranged from 3 to 7 meters. A dip bucket was used to obtain water for surface temperature measurements. Wind

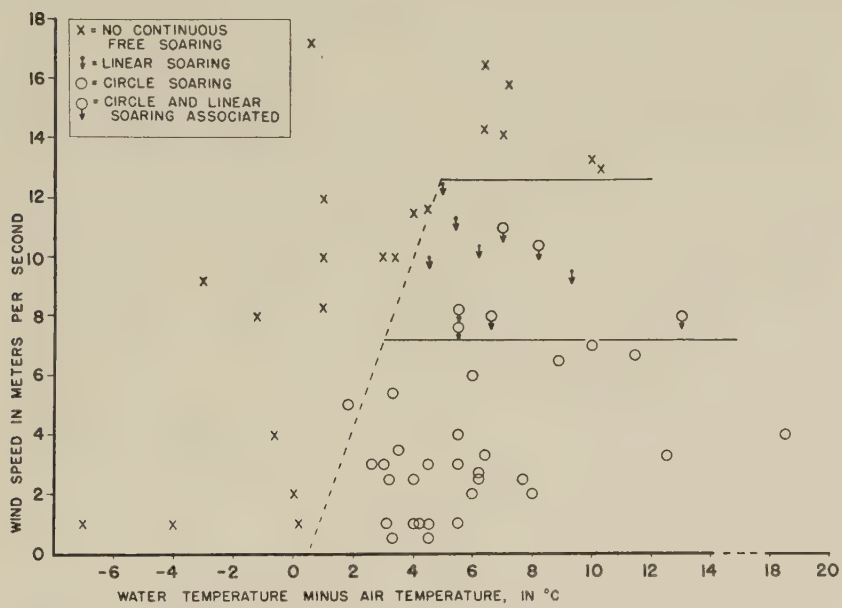

Figure 60. The flight response of herring gulls at different wind velocities and at various relative air and water temperatures.

velocity readings were made with a single anemometer at heights between 3 and 10 meters above the sea surface. Here again special precautions were taken to avoid areas where the ship's hull affected the air flow. (Correction for annemometer error has not been made, so the wind velocities are not absolute values.)

On Figure 60 the observations are plotted, with wind speed as ordinate and the temperature difference between the air and water as abscissa. Each observation represents a period of from 2 to 8 hours, with an average of about 6 hours. This does not mean that the birds were watched continuously for 6 hours, but that at any time during that period birds might have been seen performing the flight

routine which the symbol represents. The symbols on the graph differentiate three types of flight response.

One type is the absence of continuous, free soaring. *Continuous* soaring is here defined as soaring which extends over a sufficient length of time to show that the bird is not merely soaring by losing altitude. The term *free* indicates soaring which occurs independently of surface obstructions.

The second type of flight response is here called circle soaring. *Circle-soaring* is continuous, free soaring in which the birds circle about in horizontally restricted, chimney-like up-drafts, being carried along downwind (if there is a wind) at the same time.

The third type of flight may be called linear soaring. *Linear soaring* is continuous free soaring in which the birds move in a line directly against the wind flow. This soaring seems to be as nearly two-dimensional as it is possible for flight to be. Birds soaring linearly in the same up-draft are seen distributed in a vertical sheet parallel to the air flow. The thickness of the sheet seems to be not much wider than a few times the wing spread of the gulls.

The marks which are a combination of the circle and linear soaring symbols indicate that circle soaring was seen at the same time as linear soaring, though in a different location.

The scarcity of observations on the negative side of the temperature scale (Fig. 60) is not surprising when we consider the rarity of stability (U. S. Dept. of Agri. 1938, Chart No. 127) over the sea off our coast in the winter time. There was never any continuous free soaring when the air was warmer than the water. During these periods the birds spend most of their time sitting on the water, if the ship is stopped, or they alternate wing-flapping flight with resting on the water, if the ship is in motion. During periods when weak convection obtains, one often sees the birds test the up-drafts repeatedly, apparently trying to determine when the up-motion is again strong enough to make wing-flapping flight unnecessary. A few observations of frigate bird soaring among the West Indian Islands seem to show that these most efficient soaring birds use, in routine flight, convection up-drafts which apparently occur with much smaller temperature differences between the air and the water.

It will be noticed that 13 meters per second wind-speed marks the upper limit for herring gull soaring, and also that there is no linear soaring below 7 meters per second. There seems to be some very marked change in the form which the convective motion usually assumes at these two points.

Experimental work by Phillips and Walker (1932) with unstable

fluids has demonstrated that convection patterns are formed. These patterns vary; polygons being formed in horizontally motionless (without shear) fluids, with longitudinal and finally "strip-like cells" appearing as shear was introduced by horizontal flow. In unstable oil a further increase in shear caused the whole convection pattern to break down. In liquids it was found that the up-motion in the cells occurred in the centers, and the down-motion at the edges. In unstable air this was reversed, the up-motion being at the edges of the cells. In the strip-like cells formed in air, the up-moving current at the cell boundaries occurred in a sheet-like band extending up and down the direction of flow.

The change in the soaring tactics of the gulls at about 7 meters per second wind-speed, the sheet-like character of the up-drafts occurring between 7 and 13 meters per second wind-speed, and the total break-down of soaring conditions at about 13 meters per second wind speed, suggests that there is a similarity between the convection movements in the lower air and the experimental findings in unstable fluids.

Walker (1931, p. 413), in another paper in which he discusses Mal's work on forms of stratified clouds, says, "Mal's work has, I consider, transformed the interpretation of broken-up cloud layers as due to vertical instability from a plausible suggestion to an established fact; he has produced rectangular patterns and has shown that the types of cloud produced under different rates of shear resemble those formed in the laboratory." Perhaps convection patterns are also produced in the lower air, as the gulls seem to indicate.

Anticipating objections that these birds may be using some other known or unknown means of soaring, it should be brought out that there are three generally accepted (Horton-Smith, 1938, p. 98) requisites for soaring flight. If a bird is soaring, one of three things is happening: first, the air in which he soars may be rising; second, the bird may be descending; and third, the bird may be utilizing differences of horizontal velocity in the air. Here we want to show that we are dealing with the first condition.

In all of the observations here used the soaring gulls ascended many hundreds of meters into the air and stayed up for long periods of time. This quickly eliminates the second condition.

Concerning the third condition, i.e., horizontal differences of velocity in the air, Lord Rayleigh (1901, pp. 464 and 465) has said that while using "dynamical soaring" in strata of different relative velocities a bird must, upon entering one stratum, turn around until his direction is so reversed as to be with the wind of that stratum and contrary to the wind of the other stratum. But, in my observations

of circle soaring the birds turn both clockwise and counterclockwise in the same area at the same time. Soaring on differences in horizontal velocity depends upon the increase of wind with height (Idrac, 1925), and it is doubtful if this flight is possible far above the surface of the sea (Rayleigh, 1901, p. 465). But circle soaring depends upon temperature differences, and occurs hundreds of meters above the sea. Thus we see that there are several reasons why circle soaring cannot be dynamical soaring.

In linear soaring the birds do not circle, but move in an apparently straight line, and to high altitudes. This completes the elimination of numbers two and three of the required conditions for soaring flight, and leaves us with the first, i.e., up-moving air.

On January 5, 1939, at the approximate location of latitude 40° north and longitude 71° west, the "Atlantis" was in a favorable position for a measurement of an interesting down-wind tilt of an up-draft at a time when thirty or forty gulls had entered it successively. The birds were so well distributed that a rough measurement of an angle of tilt could be made with the ship's wire-angle indicator. An angle of 30° from the vertical was found. At this time the wind velocity was 6 meters per second, the water temperature 10° C., and the air temperature 3.9° C. The tops of the rising air columns appeared to be at cloud level, for occasionally birds were seen to pass through or behind wisps of cloud. During these rare occasions when many birds enter an up-draft consecutively, a sufficient portion of its extent is demarked to show that the air column has continuity, and is not just a rising bubble of unstable air. In light winds these rising columns of air closely approach the vertical. As the wind increases, they become tilted in the direction in which the air is moving.

Collecting data by noting flight variations has been a long slow process, involving hours of watching the birds go through their flight cycles and awaiting the chance coincidences of weather and nearby gulls to fill in gaps on the graph. However, if an observer could control the movements of his ship so as to remain in a region of violent meteorological change, he should be able to collect further data concerning the convection flow very quickly. Murphy (1936, see pp. 38–108) has shown the correlation between the distribution of sea birds and the great current systems of the sea and air. Soaring sea birds are also useful indicators of detailed small-scale air movements.

The occurrence of instability in the surface air over the oceans is wide-spread. In view of the possible importance of convection cells in affecting air and water movements, oceanographers should find it

useful to make a more thorough study of the convection patterns delineated by the gulls and other sea birds.

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PHYTOPLANKTON AND PLANKTONIC PROTOZOA OF THE OFFSHORE WATERS OF THE GULF OF MAINE

Part II—Qualitative Composition of the Planktonic Flora [1]

BY LOIS C. LILLICK

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ABSTRACT

The scanty winter flora of the Gulf of Maine (usually dominated by Coscinodiscus, by Ceratium, or by other small peridinians) is succeeded by the vernal outbursts of diatoms and a decrease in the abundance of peridinians. This flowering results chiefly from the rapid multiplication of Thalassiosira. The outburst starts first in the western coastal belt (February–early April); soon thereafter (March–mid-April) in the coastal and bank waters west and south of Nova Scotia, possibly also on George's Bank. The area of the Thalassiosira flowering expands northward along shore on both sides of the gulf, also southward and offshore into the eastern basin and to a certain extent into the western basin and over the eastern part of George's Bank. Active multiplication is briefest (2–4 weeks) in the eastern and southeastern parts of the gulf generally, longest in the northern coastal belt. After reaching its peak, Thalassiosira falls within a few days to an insignificant rank in the flora.

Accompanying the eclipse of Thalassiosira, there is a flowering of Chaetoceros, which lasts from 4–6 weeks over the gulf generally (i.e., until late April–May). Once its peak of abundance is passed, Chaetoceros declines as abruptly in abundance as Thalassiosira.

[1] Contribution No. 262 from the Woods Hole Oceanographic Institution; Papers from the Department of Botany of the University of Michigan No. 707.

Diatoms (though at times outnumbered by Pontosphaera) continue to dominate the flora on George's Bank throughout the summer and in some years on the northern coastal belt as well. In other years, the latter belt is dominated by a sparse peridinian flora (chiefly Ceratium) accompanied by coccolithophorids, as is the coastal belt farther south and the basin of the gulf generally, at some time between the end of May and the beginning of July.

Second flowerings of diatoms develop locally during the late summer, Rhizosolenia being frequently responsible for these in the shoaler waters including George's Bank, although Chaetoceros may have a distinct second flowering in the northern coastal belt. *Guinardia flaccida* is also an important component of the late summer flowering, especially on George's Bank, and *Sceletonema costatum* inshore. Peridinians, however, persist in undiminished numbers throughout the late summer and coccoliths are also at their maximum.

During the autumn the diatom flora is most varied and the regional contrast widest qualitatively, for with the end of active diatom proliferation, the flora gradually assumes the early winter state.

The seasonal cycle is essentially the same in the Bay of Fundy, except that Biddulphia is more important in the vernal flowering, that the vernal peaks of Thalassiosira and Chaetoceros develop later and endure longer there, and that tychopelagic and neritic diatoms are relatively more important in summer, peridinians less so.

In the Woods Hole region, the maximum flowering takes place several months earlier in the season and is chiefly of species that are of little importance in the winter-spring flora of the gulf.

The records of 1933–1934 corroborate observations that the phytoplankton cycle in the Gulf of Maine parallels that of the boreal waters of Europe in time-sequence, differing only in the association of species concerned.

Introduction

The following discussion is limited to the species that are the more important numerically in the Gulf of Maine.[2] The seasonal distribution of others of which only small numbers have been recorded, and of various tychopelagic and brackish water forms, which do not persist in the plankton of the open gulf, is presented in Tables I–III.

The Gulf of Maine Proper [3]

Earlier studies (Bigelow, 1926; Gran, 1933; Braarud, 1934; and Gran and Braarud, 1935) had already shown that the phytoplankton of the Gulf of Maine closely resembles that of the Norwegian coast and of the Skagerak in its general composition, with the same boreal species playing the major rôles from season to season. Diatoms, of which 130 species are recorded from the plankton of the gulf, constitute by far the major portion, peridinians and coccolithophorids ranking next. Phaeocystis may be dominant locally (but briefly), silicoflagellates are widespread, though seldom prominent, and the green alga Halosphaera has been recorded at many stations, though always in small numbers. The samples have also contained a few representatives of the Myxophyceae, genera Merismopedia and Gloeocapsa, as well as many small unidentified pigmented forms classed together here for convenience as "flagellates." No doubt some of these are members of the unarmored Dinophyceae, others are the spores of phytoplankton, and still others are marine green flagellates (p. 232). Fungi (spores and mycelia) were also present in small numbers in most of the collections, most abundantly at the deeper levels, but no estimate of their abundance has been attempted. Most of the spores belong to the common genera Al-

[2] For a preliminary report, including charts of numerical abundance of individual species, see Lillick (1938).

[3] For a chart of the Gulf of Maine, see Part I of this report (Bigelow, Lillick, and Sears, 1940).

TABLE I

SEASONAL DISTRIBUTION OF THE BACILLARIOPHYCEAE OF THE GULF OF MAINE

Species	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Achnanthes taeniata Grun.				×	×							
Actinocyclus Ehrenbergi Ralfs					×	×	×	×	×			
Actinoptychus undulatus (Bail.) Ralfs	×	×	×	×	×	×	×	×	×	×	×	×
Amphiprora alata Kütz.									×			
Asterionella gracillima (Hantzsch) Heib.					×							
A. japonica Cleve			×	×	×	×	×	×	×			
A. kariana Grun.				×	×	×	×	×	×			
Bacteriastrum fragilis Gran				×								
Biddulphia aurita (Lyngb.) Brèb. & God.	×	×	×	×	×	×	×	×	×	×	×	×
B. regia (Schulze) Ostf.									×			
Cerataulina Bergoni Perag.	×			×	×	×	×	×	×			
Chaetoceros spp.	×	×	×	×	×	×	×	×	×	×	×	×
Ch. affinis Laud.				×	×	×	×	×	×			
Ch. affinis var. *Willei* (Gran) Hust.				×								
Ch. atlanticus Cleve		×	×	×	×	×	×	×				
Ch. borealis Bail.	×	×	×	×	×	×	×	×	×	×	×	×
Ch. brevis Schütt							×	×		×		
Ch. ceratosporum Ostf.					×							
Ch. cinctus Gran						×	×	×				
Ch. compressus Laud.				×	×	×	×	×	×			
Ch. concavicornis Mang.				×	×							
Ch. constrictus Gran			×	×	×	×	×	×	×	×		
Ch. convolutus Castr.		×	×	×	×	×	×	×	×			
Ch. crinitus Schütt						×	×	×				
Ch. curvisetus Cleve				×	×	×						
Ch. danicus Cleve							×	×	×			
Ch. debilis Cleve			×	×	×	×	×	×	×	×		
Ch. decipiens Cleve	×	×	×	×	×	×	×	×	×	×	×	×
Ch. densus Cleve			×	×	×	×	×	×	×			
Ch. didymus Ehr.			×	×	×	×	×	×	×			
Ch. furcellatus Bail.				×	×	×						
Ch. gracilis Schütt							×					
Ch. laciniosus Schütt			×	×	×	×	×	×	×	×		
Ch. lorenzianus Grun.				×								
Ch. pelagicus Cleve												
Ch. radicans Schütt				×	×	×	×	×	×			
Ch. seiracanthus Gran				×								
Ch. similis Cleve						×						
Ch. simplex Ostf.						×	×	×	×			
Ch. socialis Laud.			×	×	×							
Ch. subsecundus (Grun.) Hust.			×	×	×	×	×	×	×			
Ch. subtilis Cleve									×			
Ch. teres Cleve			×	×	×	×	×	×				
Ch. Wighami Brightw.												
Cocconeis sp.			×									
C. placentula Ehr.	×	×	×	×	×	×	×	×	×	×	×	×

TABLE I (*Continued*)

Species	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
C. Scutellum Ehr.			×				×	×				
Corethron hystrix Hensen	×			×	×	×	×	×	×			×
Coscinodiscus spp.	×	×	×	×	×	×	×	×	×	×	×	×
C. argus Ehr.		×										
C. asteromphalus Ehr.			×	×	×	×	×	×	×	×		
C. centralis Ehr.	×	×	×	×	×	×	×	×	×	×	×	×
C. cinctus Kütz.					×				×			
C. concinnus W. Smith			×	×	×	×	×	×				
C. curvatulus Grun.			×	×	×							
C. excentricus Ehr.	×	×	×	×	×	×	×	×	×	×	×	×
C. lineatus Ehr.				×			×	×				
C. osculis-iridis Ehr.			×	×				×	×	×		
C. radiatus Ehr.			×	×	×		×	×	×			
C. stellaris Roper							×					
Coscinosira Oestrupi Ostf.				×	×	×	×	×	×			
C. polychorda Gran				×	×	×	×	×	×			
Cyclotella sp.	×											
Dactyliosolen mediterraneus Perag.								×				
Detonula confervacea (Cleve) Gran	×		×	×	×	×	×					
Ditylium Brightwelli (West) Grun.		×	×	×	×	×	×	×	×	×		
Endictya oceanica Ehr.				×	×	×						
Eucampia recta Gran & Braarud						×		×				
E. zoodiacus Ehr.		×		×	×	×	×	×				
Eunotia arcus Ehr.				×								
Fragilaria sp.				×								
F. cylindrus Grun.				×			×	×				
F. oceanica Cleve				×								
Grammatophora marina (Lyngb.) Kütz.							×	×	×			×
Guinardia flaccida (Castr.) Perag.	×	×				×	×	×	×			
Hemiaulus Hauckii Grun.							×					
Leptocylindrus danicus Cleve	×			×	×	×	×	×	×			
L. minimus Gran					×	×	×	×	×			
Lichmophora abbreviata Ag.							×	×				
L. Juergensii Ag.								×				
Melosira sp.	×			×								
M. italica (Ehr.) Kütz.							×	×				
M. sulcata (Ehr.) Kütz	×	×	×	×	×	×	×	×	×	×	×	×
Navicula sp.	×	×	×	×	×	×	×	×	×	×	×	×
N. distans W. Smith	×	×	×	×	×	×	×	×	×	×		
N. Vanhoeffeni Cleve			×	×								
Nitzschia sp.		×										
N. Closterium W. Smith	×	×	×	×	×	×	×	×	×			
N. delicatissima Cleve			×	×	×	×	×	×	×			
N. longissima Cleve	×					×	×	×				
N. seriata Cleve	×	×	×	×	×	×	×	×	×			
Pinnularia spp.						×			×			
Pleurosigma spp.	×	×	×	×	×	×	×	×	×	×	×	×
Pleurosigma angulatum (Quek.) W. Smith							×	×				

TABLE I (*Continued*)

Species	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
P. balticum (Ehr.) W. Smith							×	×				
P. decorum W. Smith							×	×				
P. elongatum W. Smith							×	×				
P. fasciola (Kütz.) W. Smith							×	×				
P. Normani Ralfs	×	×	×	×	×	×	×	×	×	×	×	×
Porosira glacialis (Grun.) Jörg			×	×	×	×	×	×				
Raphoneis amphiceros Ehr							×					
R. surirella (Ehr.) Grun			×			×						
Rhabdonema adriaticum Kütz							×	×				
R. arcuatum (Lyngb. ? Ag.) Kütz						×	×	×				
Rhizosolenia spp	×	×	×	×	×	×	×	×	×	×	×	×
Rh. alata Brightw	×	×	×	×	×	×	×	×	×	×	×	×
Rh. Bergonii Perag				×								
Rh. calcar-avis M. Schultze								×				
Rh. fragilissima Berg				×	×	×	×	×	×			
Rh. hebatata var. *semispina* (Hensen) Gran		×	×	×	×	×	×	×	×	×		
Rh. imbricata var. *Shrubsolei* (Cleve) Schröd		×	×	×	×	×	×	×	×	×		
Rh. setigera Brightw			×	×	×	×	×	×	×	×		
Rh. styliformis Brightw			×	×	×	×	×	×				
Sceletonema costatum (Grev.) Cleve	×	×	×	×	×	×	×	×	×	×	×	×
Stephanodiscus astrea (Ehr.) Grun			×									
Stephanopyxis turris. (Grev. & Arn.) Ralfs							×					
Streptotheca thamesis Shrubs						×	×	×	×			
Synedra Gaillonii (Bory) Ehr							×	×				
Tabellaria fenestrata (Lyngb.) Kütz							×	×				
Thalassionema nitzschioides Grun	×	×	×	×	×	×	×	×	×	×	×	×
Thalassiosira spp	×	×	×	×	×	×	×	×	×	×	×	×
Th. baltica (Grun.) Ostf			×									
Th. bioculata (Grun.) Ostf			×	×	×	×			×			
Th. decipiens (Grun.) Jörg	×	×	×	×	×	×	×	×	×	×	×	×
Th. gravida Cleve			×	×	×	×	×	×	×			
Th. hyalina (Grun.) Gran			×	×	×				×	×		
Th. Nordenskioeldi Cleve	×	×	×	×	×	×	×	×	×	×	×	×
Th. subtilis (Ostf.) Gran			×									
Thalassiothrix Frauenfeldii Grun						×	×	×				
Th. longissima Cleve & Grun			×	×	×	×	×	×	×	×		
Triceratium alternans Bail	×								×			

ternaria and Aspergillus, possibly some to Monilia. These may have come from the air, but Sparrow's (1937) observations make it likely that most of them were in the water. The chief contribution from the data for 1933–1934 is as regards the numerical relationships.[4]

Early Winter Flora

The flora of the gulf as a whole is not only very scanty but most nearly uniform at this season, though the relative importance of the individual species may vary considerably

[4] For details as to the collections and method of analysis see Part I of this report, p. 150.

TABLE II

SEASONAL DISTRIBUTION OF THE DINOPHYCEAE OF THE GULF OF MAINE

Species	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Amphidinium spp.					×							
A. oceanicum Lohm.									×			
Ceratium arcticum (Ehr.) Cleve	×	×	×	×	×	×	×	×				
C. bucephalum (Cleve) Cleve			×	×	×	×	×	×	×			
C. Fusus (Ehr.) Duj.	×	×	×	×	×	×	×	×	×	×	×	×
C. lineatum (Ehr.) Cleve	×			×	×	×	×	×	×	×	×	×
C. longipes (Bail.) Gran	×	×	×	×	×	×	×	×	×	×	×	×
C. macroceros (Ehr.) Cleve								×	×	×		
C. tripos (O. F. M.) Nitzsch	×	×	×	×	×	×	×	×	×	×	×	×
C. tripos var. *atlanticum* Ostf.								×				
C. tripos f. *subsalsum* Ostf.								×				
Dinophysis spp.				×	×	×	×	×	×	×	×	×
D. acuminata Clap. & Lach.				×	×	×	×	×	×			
D. acuta Ehr.								×				
D. arctica Mereschkowsky				×	×							
D. longi-alata Gran & Braarud				×	×							
D. norvegica Clap. & Lach.				×	×	×	×	×	×			
D. Ovum Schütt				×	×	×	×	×	×	×		
D. robusta Gran & Braarud				×	×			×	×			
D. sphaerica					×					×		
Exuviaella spp.	×								×	×	×	×
E. baltica Lohm.	×	×	×	×	×	×	×	×	×	×	×	×
E. marina Cienkowski	×	×	×		×				×	×		
E. perforata Gran								×				
Glenodinium spp.				×	×							
G. danicum Paulsen							×	×				
G. lenticulata (Bergh) Schiller				×	×		×	×	×			
Goniaulax spp.				×	×					×	×	
G. digitale (Pouchet) Kofoid							×	×				
G. orientalis Lindemann								×				
G. spinifera (Clap. & Lach.) Diesing								×	×			
G. tamarensis Lebour			×	×	×	×	×	×	×	×	×	×
G. triacantha Jörg.					×	×	×	×	×			
Gymnodium spp.				×	×	×						
G. Lohmanni Paulsen				×	×	×			×			
Mesoporos asymmetricus (Schiller) Lillick										×		
M. perforatus (Gran) Lillick												×
Noctiluca Miliaris Sur.					×			×				×
Oxytoxum sp.						×						
O. gracile Schiller								×				
O. reticulatum (Stein) Schütt								×				
Peridinium spp.	×	×	×	×	×	×	×	×	×	×	×	×
P. achromaticum Levander								×	×			
P. americanum Gran & Braarud				×	×				×	×		
P. breve Paulsen			×		×				×	×		
P. brevipes Paulsen				×	×	×	×	×	×			

TABLE II (*Continued*)

Species	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
P. conicoides Paulsen				×	×	×	×	×	×	×	×	×
P. conicum (Gran) Ostf. & Schmidt				×	×	×	×	×	×			
P. conicum var. *Asamushi* Abé					×	×			×	×	×	×
P. crassipes Kofoid								×				
P. curvipes Ostf.				×	×							
P. denticulatum Gran & Braarud			×	×	×				×	×		
P. depressum Bail.			×	×	×	×	×	×	×	×	×	×
P. divergens Ehr.				×	×	×	×	×	×			
P. excentricum Paulsen								×				
P. Granii Ostf.	×		×		×	×	×	×	×	×		
P. globulus Stein									×			
P. globulus var. *ovatum* (Pouchet) Schiller				×	×	×	×	×	×			
P. globulus var. *quarnerensis* Br. Schröder				×	×	×	×	×	×			
P. hangoei Schiller				×	×	×						
P. minusculum Pav.	×						×	×				×
P. monacanthum Broch.				×	×							
P. obtusum Karsten							×	×				
P. pallidum Ostf.								×	×	×		
P. pellucidum (Bergh) Schütt				×			×	×				
P. pentagonum Gran					×				×			
P. pyriforme Paulsen				×				×				
P. roseum Paulsen				×	×	×	×	×				
P. rotundum (Lebour) Schiller							×	×				
P. simplex Gran & Braarud	×	×	×	×	×	×			×	×		
P. Steinii Jörg.						×		×	×			
P. subinerme Paulsen							×	×				
P. Thorianum Paulsen				×	×							
P. triquetrum (Ehr.) Lebour			×	×	×	×	×	×	×			
P. trochoideum (Stein) Lemm.			×	×	×	×	×	×	×			
P. variegatum Peters					×							
Phalocroma parvulum (Schütt) Jörg.	×		×									
Prorocentrum micans Ehr.	×				×			×	×	×	×	×
P. minimum Schiller												×
P. Scutellum Schröder				×	×	×	×	×				
Protoceratium reticulatum (Clap. & Lach.) Butschli								×				
Pyrophacus horologium Stein								×				

in different parts of the gulf even then (Fig. 1). Species dominant in the winter flora are:

Coscinodiscus excentricus	(temperate neritic)
C. centralis	(boreal oceanic)
Thalassionema nitzschioides	(boreal neritic)
Ceratium longipes	(boreal oceanic)
C. tripos	(temperate oceanic)
Prorocentrum micans [5]	(temperate neritic).

[5] *P. micans* has also been recorded in small numbers in spring and more abundantly at Woods Hole in summer (Fish, 1925).

TABLE III

SEASONAL DISTRIBUTION OF THE COCCOLITHOPHORIDACEAE, SILICATAE, ET AL. OF THE GULF OF MAINE

Species	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Acanthoica acanthifera Lohm.						×			×			
A. acanthos Schiller	×	×	×			×			×	×	×	×
A. coronata Lohm.			×									
A. monospina Schiller			×						×			
Calyptrosphaera oblonga Lohm.									×			
C. uvella Schiller			×									
Coccolithus pelagicus (Wall.) Schiller	×			×	×	×	×	×	×			
Discosphaera tubifer (Murr & Blackman) Lohm.			×									
Lohmanosphaera spp.	×		×									
L. adriatica Schiller			×									
Pontosphaera Bigelowi Gran & Braarud								×	×			
P. Huxleyi Lohm	×		×		×	×	×	×	×	×		
P. ovalis Schiller	×											
Rhabdosphaera stylifer Lohm.	×		×						×	×		
R. tubulosa Schiller	×											
Scyphosphaera Apsteini Lohm.			×									
Syracosphaera spp.			×					×	×			
S. mediterranea Lohm.			×									
S. pulchra Lohm.									×	×		
Dictyocha fibula Ehr.	×		×			×	×	×	×	×		
D. fibula var. *messanensis* (Haek.) Lemm.						×						
D. fibula f. *spinosa* Lemm.					×							
Distephanus speculum (Ehr.) Haek.	×			×	×	×	×	×	×			
Ebria antiqua Schulz												×
E. tripartita (Schum.) Lemm.				×			×	×	×			
Gloeocapsa spp.	×								×			
Merismopedia spp.	×											
Halosphaera viridis Schmitz					×	×	×	×	×	×		
Eutreptia Lanowi				×	×	×	×	×	×			
Phaeocystis spp.				×	×							
Flagellates	×	×	×	×		×			×	×	×	×

In the year 1933 the diatom genus Coscinodiscus,[6] and most commonly but not invariably *C. excentricus* was dominant in the western and northern coastal belts, forming up to 48% by number of the total (up to 1,700 cells per liter locally, near the tip of Cape Cod) accompanied by Ceratium, smaller peridinians etc. in the numerical proportions shown in Fig. 2. Coscinodiscus also dominated in the western side of the basin (Fig. 1) in about the

[6] Thirteen species of Coscinodiscus have been found in the gulf (Table I), but only 3 of them are significant items in the plankton, i.e., *C. excentricus*, *C. centralis* and *C. asteromphalus*, all of which are similar as to distribution.

same proportion, with Ceratium very scarce (less than 50 cells per liter), but with other peridinians in moderate abundance (about 300 per liter). On the eastern side of the Gulf, however, Coscinodiscus formed not more than 10%, the dominants being species of Peridinium and of Exuviella (about 500 per liter) accompanied by neritic diatoms, chiefly *Melosira sulcata* and *Thalassionema nitzschioides* (not more than 250 per liter, Fig. 2). The one station for the month on George's Bank (eastern part) suggests dominance at the time by a more complex flora—with Ceratium, other peridinians, Coscinodiscus and various neritic diatoms in more nearly equal proportions (Fig. 2).

Essentially the same mutual relationship of the dominant members, i.e., Coscinodiscus, other neritic diatoms, Ceratium and other Peridinians, appears to have persisted at least through January of the winter in question, to judge from the close correspondence between

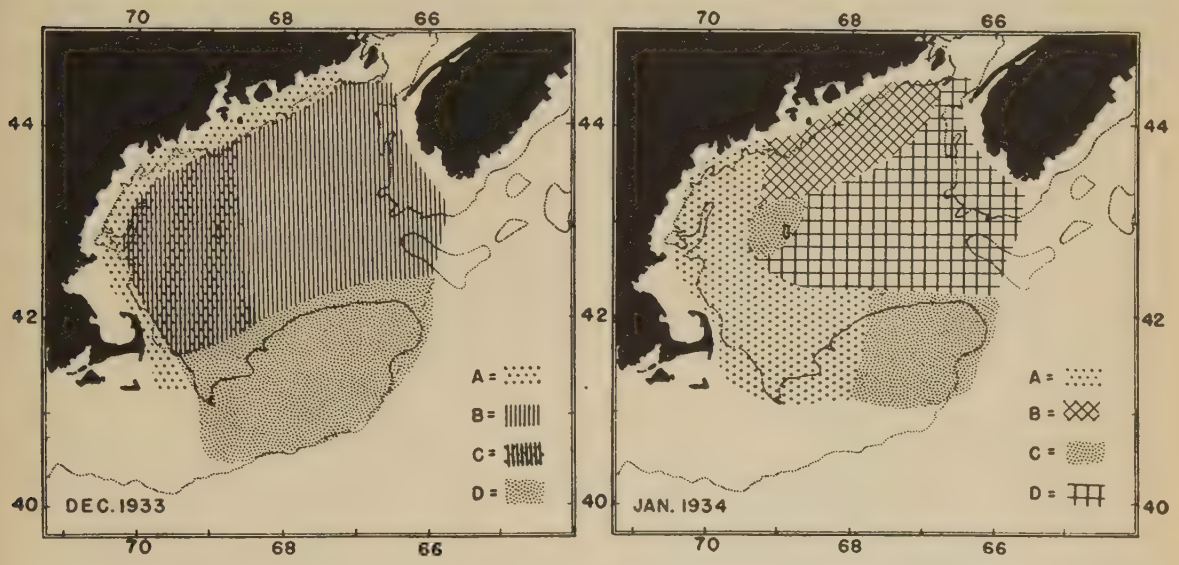

FIG. 1. Distribution of phytoplankton communities in the Gulf of Maine. December 1933 (left); *A*, Coscinodiscus; *B*, Peridinians; *C*, Coscinodiscus and peridinians; *D*, Neritic diatoms, plus mixture of Coscinodiscus and peridinians. January 1934 (right); *A*, Coscinodiscus; *B*, Sceletonema and neritic diatoms; *C*, Winter neritic diatom and peridinian community; *D*, Phytoplankton nearly or completely absent.

the percentages at corresponding stations for that month with those for December (Figs. 1, 2). Only on George's Bank may there have been any marked alteration, i.e., development of dominance by Thalassionema—nor is it certain that even this indicates any significant alteration, the January station having been located on the western part, the December station on the eastern.

It is during the mid-winter that the diatom genus Coscinodiscus attains its richest development, for although it has no definite flowering in the sense of that of Thalassiosira, Chaetoceros or even Rhizosolenia, it so increases in numbers from October on, at a time when other diatoms are disappearing from the waters, that the winter counts are frequently 50–100% Coscinodiscus. Because of its large size the genus also frequently dominates volumetrically in samples in which it is not numerically important. Data for earlier years suggest, however, that during the winter of 1933–1934 dominance by Coscinodiscus involved a greater proportion of the gulf than is usual, for in late December and early January

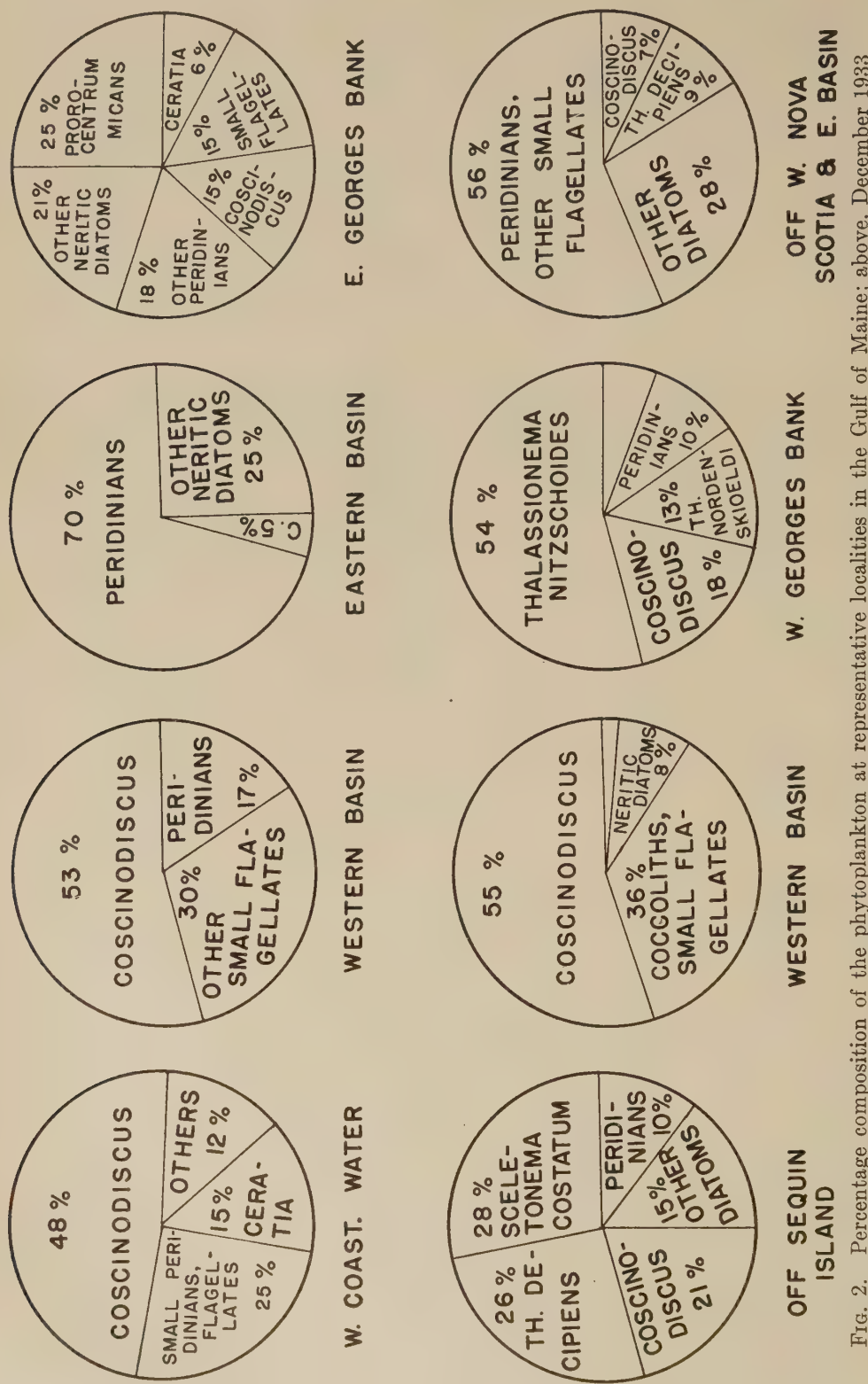

FIG. 2. Percentage composition of the phytoplankton at representative localities in the Gulf of Maine; above, December 1933 (C. = Coscinodiscus); below, January 1934.

of 1920–1921, it was dominant at one of the stations occupied by the "Halcyon" along the western and northern shores of the gulf, i.e., near the mouth of the Merrimac River, but was less important than Ceratium (though still the most numerous diatom) in the eastern side of the basin, in the Fundy deep and off western Nova Scotia (Bigelow, 1926, p. 395). Coscinodiscus was, in fact, only a minor element in the vicinity of Cape Ann in the winter of 1912–1913, *Ceratium tripos* (with occasional *C. Fusus* and peridinians) being dominant at the end of November and December with only occasional diatoms (Coscinodiscus, Rhizosolenia, Chaetoceros); and codominant with the diatoms Chaetoceros and *Thalassiothrix nitzschioides* in January (Bigelow, 1914, p. 404).

Midwinter Modifications

One or other of the following species of diatoms (mainly boreal)—some of which are so scarce during the early winter that only a few chance specimens appear in collections—may show enrichment in late December or January, either in the western coastal belt or on the southern rim of the gulf:

Biddulphia aurita	(boreal neritic)
Chaetoceros atlanticus	(boreal oceanic)
Ch. borealis	(boreal oceanic)
Ch. convolutus	(boreal oceanic)
Ch. decipiens	(boreal oceanic)
Ch. densus	(temperate oceanic)
Eucampia zoodiacus	(temperate neritic)
Leptocylindricus danicus	(boreal neritic)
Melosira sulcata	(boreal tychopelagic)
Rhizosolenia alata	(temperate oceanic)
Rh. hebatata var. *semispina*	(boreal oceanic)
Sceletonema costatum	(boreal neritic)
Thalassionema nitzschioides	(boreal neritic)
Thalassiosira decipiens	(boreal neritic)
Thalassiothrix longissima	(boreal oceanic).

The magnitude of this development may be illustrated for 1934 by the accompanying table for George's Bank:

Species	Cells/liter, December, 1933	Cells/liter, January, 1934
Melosira sulcata	90	287
Thalassionema nitzschioides	265	2795
Coscinodiscus excentricus	200	200
Other neritic diatoms	65	1225
Peridinians	990	550

A mild flowering of *Rhizosolenia alata* also takes place in winter in the inner parts of the gulf, at least locally. In 1925 for example, *R. alata* dominated in Cape Cod Bay from mid-November through January and early February, and in 1934 Rhizosolenia occurred

in numbers as high as 1,300 per liter (16% of the total population) off western Nova Scotia in March (Fig. 3). Fish (1925) also found a regular winter flowering of *Rhizosolenia alata* at Woods Hole, but it is not likely that this contributes to its winter peak in the western coastal belt of the gulf, since *R. alata* has not been found on the southern banks at this season. On the other hand a distinct maximum (up to 4000 cells per liter) was recorded there in March 1934 for *Thalassionema nitzschioides*, a neritic species which usually occurs only in small numbers in the open gulf, although it has been one of the most regularly recurrent members of the gulf plankton during most of the months of record, and there is some evidence that Thalassionema, like Rhizosolenia and Sceletonema, may have two flowering periods in the gulf—the one in early spring, the other in early autumn (p. 222).

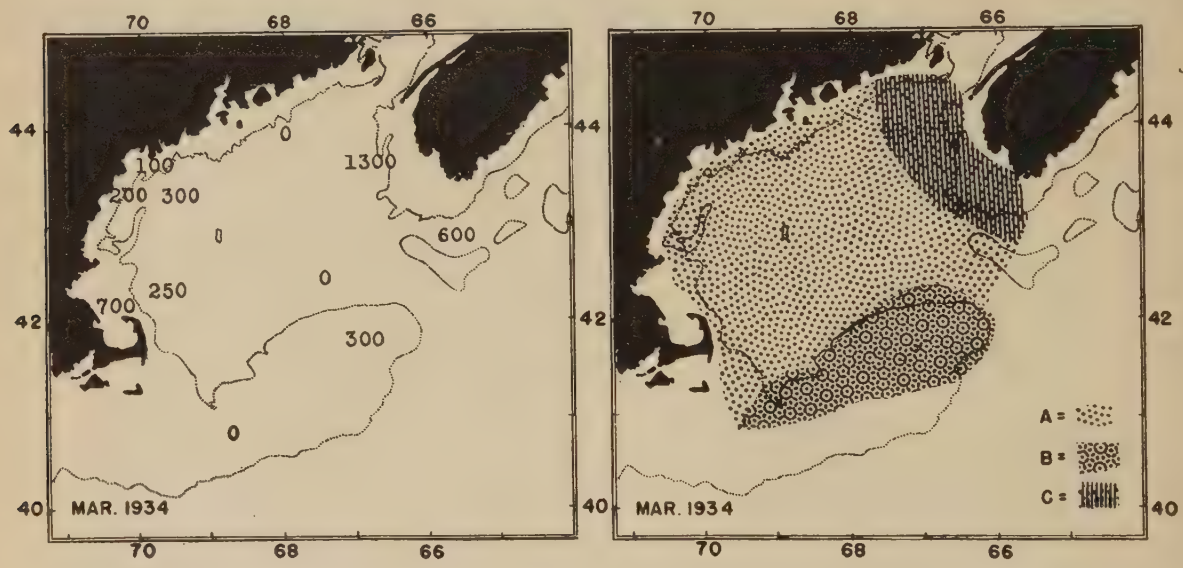

Fig. 3. Left: *Rhizosolenia alata* in March 1934, expressed as the number of cells per liter at the level of maximum abundance, usually the surface. Right: Distribution of phytoplankton communities in the Gulf of Maine, March 1934;—*A*, Thalassiosira; *B*, Littoral and neritic diatoms; *C*, Thalassiosira and Dinophyceae.

Sceletonema costatum also multiplied to about 500 cells per liter in the northern coastal waters of the gulf, i.e., near Seguin Island in January of 1934, a stock sufficient to make the species characteristic of the regions which it inhabits though far smaller than that which develops in European waters in early spring (Fig. 2); whereas it was either absent or only occasional on the western side of the gulf or over the southern banks at the time. Multiplication of Chaetoceros may also take place in late January and February in some years, for although we have no evidence of this for 1934, *Ch. atlanticus*, *Ch. convolutus* and *Ch. decipiens* (combined) dominated the entire basin in late February and early March of 1920, and its western branch as late as mid-April (Bigelow, 1926, p. 421). In 1913 Chaetoceros increased in importance relative to Ceratium from December through January, and probably in abundance as well, though counts were not made (Bigelow, 1914, p. 404).

The tychopelagic form *Actinoptychus undulatus*, which has been recorded at many stations, was codominant with Coscinodiscus and with *Biddulphia aurita* near Seal Island,

Nova Scotia, on March 23, 1920, other diatoms still being very few in number (Bigelow, 1926). The chain-forming *Navicula Vanhoeffeni*, though an arctic neritic form, was listed for April of 1932 by Gran and Braarud (1935) and was relatively abundant over the banks and in the coastal waters in March 1934, with a maximum of 4,600 cells per liter on the western part of George's Bank. A scattering of other naviculas—most commonly *N. distans*—have also been recorded at many stations in most of the months of record, in greater abundance in the Bay of Fundy than in the open gulf (Gran and Braarud, 1935); no doubt they are swept up from the bottom by the tidal currents. A diatom community of unusual composition, marked by a large variety of species of diatoms and peridinians and contrasting with the sparse flora in the surrounding waters, but similar to the flora on George's Bank at the time though not continuous with it, was encountered in the western basin near Cashes Ledge in January 1934. This same area has also been found to support exceptional associations of phytoplankton at other seasons (p. 214).

Coincident with this rise in numbers for neritic diatoms, the Dinophyceae decrease during the late winter, as shown for 1934 by the accompanying table, with the result that the net increase in the total number of vegetable cells is small (p. 155, Pt. I).

PERCENTAGE OF POPULATION

	Western Coastal Waters		George's Bank	
	December	January	December	January
Neritic diatoms	7%	70%	21%	75%
Coscinodiscus	50%	20%	15%	15%
Peridinians	20%	4%	48%	8%

The chief variations recorded from year to year in the character of the mid- and late winter flora are in the relative abundance of Coscinodiscus as compared with Ceratium and with other peridinians as just described, and in the abundance of neritic diatoms of the species enumerated above, any one of which may become dominant temporarily in one part of the gulf or another.

Spring Flora

The spring ushers in such sudden changes in the composition of the flora that it then enters upon the most interesting successional stages of its yearly cycle, even apart from the great outburst of growth (p. 156). The most obvious change from the winter state lies in the outburst of diatoms, but of species other than those characteristic of the preceding communities, for the latter (with few exceptions) are either absent from the vernal associations or of small importance in them. On the other hand peridinians continue to diminish in numbers as the spring advances, until the vernal diatoms reach their peak of development, when only occasional individuals are found. This impoverishment of peridinians cannot be attributed to their being crowded out by the rapidly dividing diatoms, since in 1920 it took place nearly simultaneously over all but the southeast corner of the gulf, at a season when the rich diatom flowerings were still restricted to rather definite centers, i.e., to the coastal waters, to the shallows of Brown's and German Banks, to the intervening

channel and to the continental slope (Bigelow, 1926). Similarly in 1934 the peridinians had practically vanished from the gulf by the latter part of March, except off western and southern Nova Scotia where they still persisted in numbers not exceeding 1,100 per liter, though the diatoms had so far multiplied only in the western and northwestern coastal belt.

The spring flora is foreshadowed by the appearance of *Thalassiosira decipiens* and *Th. Nordenskioeldi* in small quantities, but widespread over the gulf in late winter (about 100–400 cells per liter in January 1934), *Th. decipiens* usually developing first, as it does in the Bay of Fundy also (Gran and Braarud, 1935), but reaching its maximum concurrently with *Th. Nordenskioeldi* (pp. 197, 207, Table I) (Fig. 4 [7]), rarely becoming a major element in the flora. It is now established that the flowering of Thalassiosira, for which *Th. Nordenskioeldi* is chiefly responsible in the gulf proper, originates just after the waters have reached their coldest, in shallow water in two chief centers, one along the narrow coastal sector between Boston Harbor [8] and Portland, the other in the coastal and bank waters south of Nova Scotia (Table IV). It is in the first of these centers that flowerings have been recorded earliest, i.e., before the end of February in 1920 and 1925, about mid-March in 1934, 1938 and 1939, but not until early April in 1913. In the Nova Scotian center this stage is not reached until two to four weeks later, or until the end of March in an early year (e.g., 1920), but not until about the middle of April in a late one, as in 1934, with early April as the average.

Thalassiosira, or that genus plus Chaetoceros, was also found in moderate abundance on George's Bank in the last half of April of 1913 and 1915. It is doubtful, however, whether it ever flowers there in such abundance as it does to the northward, for the rich flora encountered to the southwest part of the bank in late February and again in May of 1920 was dominated by *Chaetoceros socialis*, with other neritic diatoms in smaller numbers (Bigelow, 1926). Again in 1934 *Th. Nordenskioeldi* was in only moderate numbers (950 per liter), subordinate to other neritic diatoms on the southwestern part of the bank in January and less numerous in March (265 cells per liter), while the western part of the bank was dominated early in that May by the same Chaetoceros community that usually succeeds Thalassiosira in other parts of the gulf. Thus, if any active flowering of Thalassiosira took place on the bank during that particular spring, its course must have been run between the first and the last of April.

The flowering of Thalassiosira expands first along shore from the Boston-Cape Elizabeth center in both directions. In 1920 it had involved Massachusetts Bay and Cape Cod Bay by the end of the first week of April, i.e., within four weeks of its inception. It also reaches to the offing of Casco Bay at about the same time (to judge from 1920), expanding thence eastward to the Fundian region, where *Th. Nordenskioeldi* usually reaches its peak of development by the latter half of April. Such at least was the case in 1920 (Bigelow, 1926), in 1932 (Davidson, 1934; Gran and Braarud, 1935) and in 1934 (Fig. 5).

The eastern flowering also expands northward (usually) by the latter half of April to join the western flowering off the mouth of the Bay of Fundy; southward across Brown's Bank; and westward as well over the eastern side of the bowl generally, where more than

[7] At certain stations very close to shore neritic species of Chaetoceros may equal Thalassiosira in importance in early spring but only rarely farther from shore, until later in the season.

[8] The earliest flowering was north of Cape Ann in 1913 (Bigelow, 1926), but collections made in 1938 and 1939 have shown that the waters on the northern side of Massachusetts Bay likewise contribute to it.

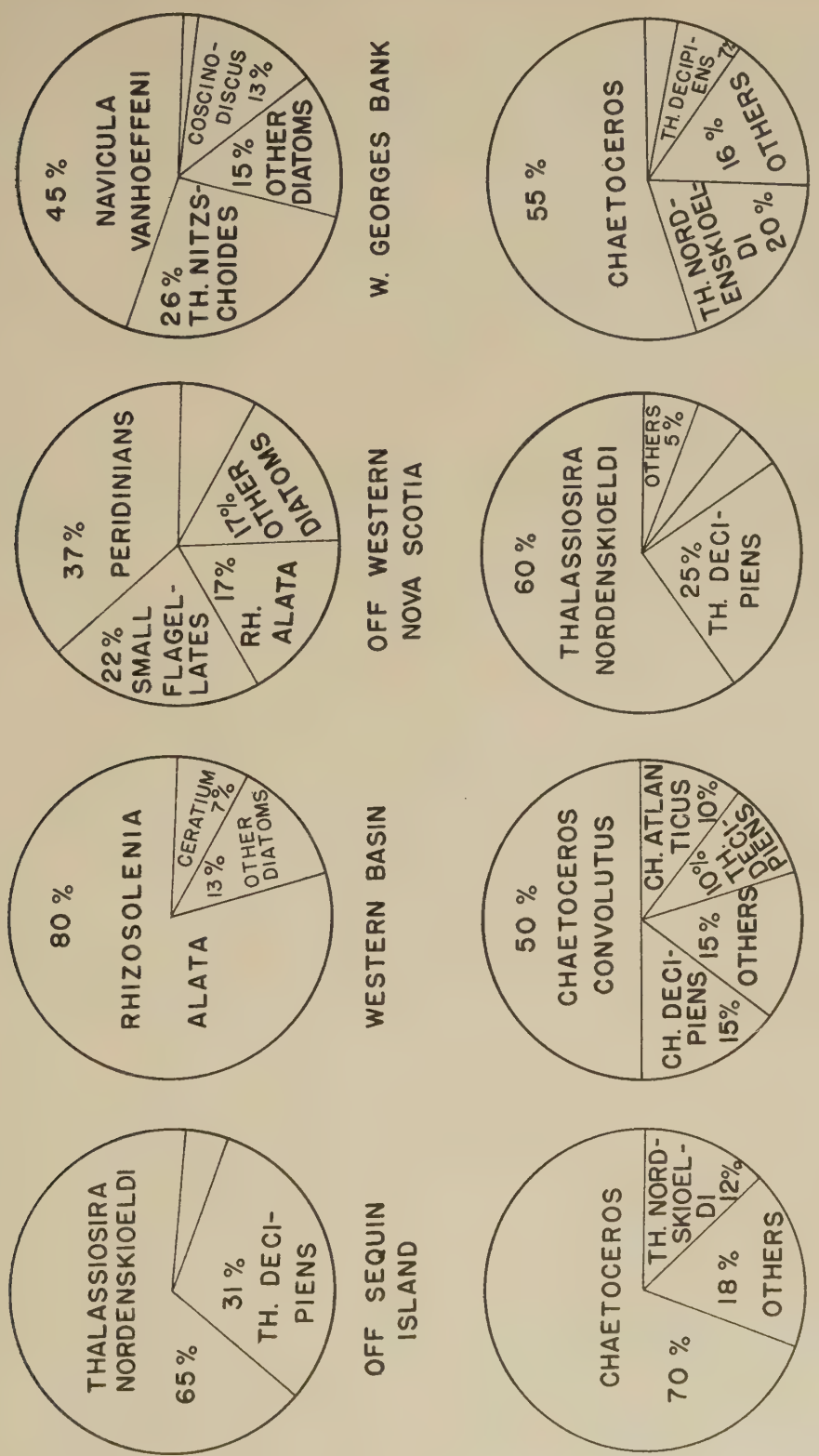

Fig. 4. Percentage composition of the phytoplankton at representative localities in the Gulf of Maine in 1934;—March (above) and late April–early May (below).

50% of the total number of cells in the richest diatom flowering yet recorded for the gulf were *Th. Nordenskioeldi* in late April of 1934, with related species accounting for an additional 30% (Fig. 4). It is probable that this is a regular yearly event in that general locality, as it is elsewhere in the gulf, for although no very rich flowering of Thalassiosira was encountered on the eastern side of the basin in 1920, whether in April or in May, it is likely that the cruises of that spring merely failed to coincide in date there with the vernal outburst.

In 1934 Thalassiosira increased in numbers in the western basin from 100 per liter in late March to between 100,000 and 200,000 in late April, though still forming little more than 10% of the total phytoplankton (Fig. 4); and it was also very prominent in the rich diatom florae encountered in one part or another of the western basin after the middle of April of 1915 and 1920, though similarly outnumbered by Chaetoceros. It may be that

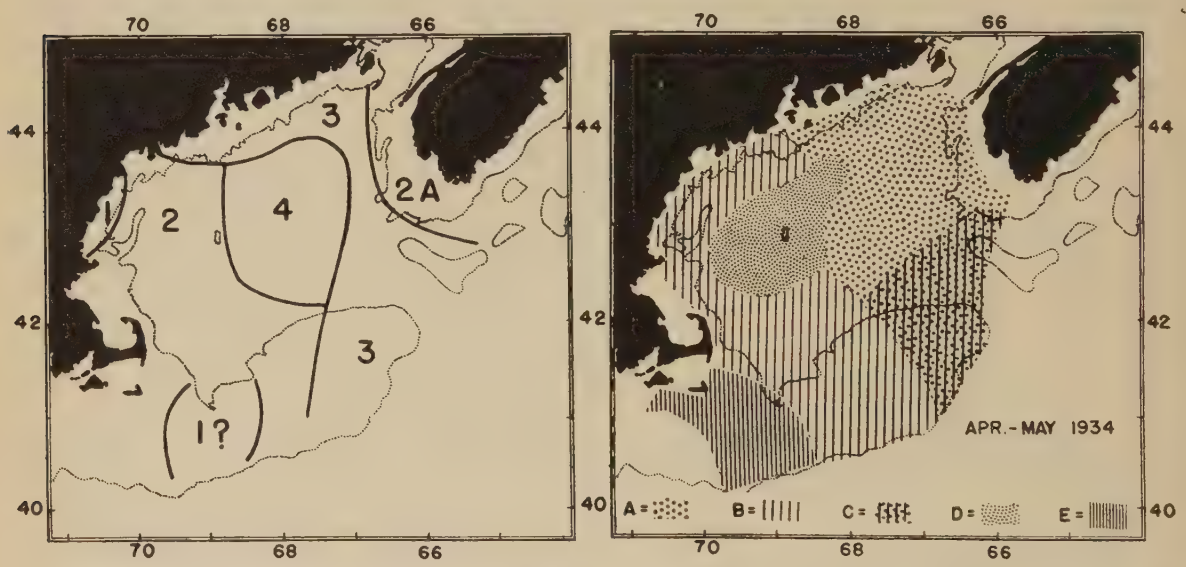

Fig. 5. Left: Successive stages of the Thalassiosira maximum in the Gulf of Maine. Right: Distribution of phytoplankton communities in the Gulf of Maine, late April–early May; *A*, Thalassiosira dominant, Chaetoceros minor; *B*, Chaetoceros dominant, Thalassiosira minor; *C*, Thalassiosira and Chaetoceros codominant; *D*, *Chaetoceros convolutus; E*, peridinians.

this mixed community develops directly as such in the western basin, but inasmuch as the vernal flowering of Chaetoceros in other parts of the gulf usually coincides with the eclipse of Thalassiosira, it is equally possible that the peak for the latter fell between the dates of the cruises in the western basin, as well as in the eastern. The fact that the flowering of Thalassiosira does not take place over all the gulf simultaneously (Table IV) makes it likely, indeed, that each survey has missed certain of these stages in some region.

The anticlockwise character of the dominant drift must condition the dispersal of Thalassiosira from its center of most active production. The flowering that originates in the western coastal belt may likely spread to Massachusetts and Cape Cod Bays and to parts of the western basin. Thalassiosira might similarly spread eastward over George's Bank from the west, though hardly from the western part of the latter to the open basins

to the northeast; and the seeding of the eastern basin may be from the Nova Scotian shallows. It has already been suggested (Bigelow, 1926) that the Thalassiosira-Chaetoceros flora encountered on the eastern part of George's Bank, and to the northward toward Nova Scotia in mid-April of 1920, had its origin in the vernal Scotian drift from the east. But for Thalassiosira to spread from the Cape Ann-Cape Elizabeth sector eastward along the coast toward the Bay of Fundy would be directly against the dominant current. With small numbers of the genus present and widespread over the gulf during the months prior to its vernal outburst, it is more probable that the successive development of its peaks of abundance in different regions results chiefly from increasing activity of local reproduction, commencing as early in the season as the conditions of life become favorable for this diatom in any particular region.

Composition of the Thalassiosira Community

Thalassiosira Nordenskioeldi plays as dominating a rôle in the gulf as it does in the seas of northern Europe, though flowering only in early spring. Present in numbers not greater than 5,000 cells per liter in summer, and rarely more than 500 in autumn or winter, it frequently increases to more than a million per liter and to about eight billion per column in April–May. During its peak season it is regularly accompanied by *Th. decipiens*, by *Th. gravida* and by *Porosira glacialis* (p. 197), which have the same general seasonal cycle. On two occasions *Th. decipiens* was found somewhat more numerous than *Th. Nordenskioeldi*, i.e., near Seguin Island in late March 1920, and again late in April of 1934. In the latter case the codominance by *Th. decipiens* extended eastward to the ridge which separates the western basin from the eastern, where its abundance (45% of the total population and maximum of nearly 1 million cells per liter) about equalled that of *Th. Nordenskioeldi* (44%). Gran and Braarud's (1935, p. 367) statement that in 1932 decipiens "was by far the commonest of all diatoms . . . observed at all seasons . . . and nearly at every station" in the Bay of Fundy region (their observations covering March to September only), is evidence that its relative importance may increase northward, though the maximum recorded by them for that spring was only about 12,000 per liter. *Thalassiosira gravida* was recorded in abundance as great as 100,000 cells per liter in the northern part of the gulf in April by Gran and Braarud (1935), and Bigelow (1926) ranked it and not decipiens as second to Nordenskioeldi in collections made in the spring. *Th. bioculata* and *Th. hyalina* also appear in spring—are in fact limited to that season (Table I)—but neither of them attains any numerical prominence in the flora of the gulf.

Porosira glacialis,[9] a regular and important member of the Thalassiosira plankton in European waters, flowers but briefly in the Gulf of Maine, usually in late March or April, concurrent with Thalassiosira or just after the latter. It is not of importance after April, but has been found occasionally and in small numbers in May, June and August. The maximum count for it in 1934 was about 28 million cells per column and 7,050 per liter in March, but Gran and Braarud (1935) report a maximum of nearly 30,000 per liter.

Other species commonly associated with Thalassiosira flora are *Chaetoceros atlanticus*, *Ch. borealis*, *Ch. convolutus*, *Ch. debilis*, *Ch. decipiens*, *Ch. compressus*, *Ch. laciniosis* and

[9] The species for April under this name in the preliminary report (Lillick, 1938) was in reality *Thalassiosira decipiens*.

Ch. furcellatus, all of which have a seasonal distribution very similar to that of *Th. Nordenskioeldi;* also *Leptocylindricus danicus* and *L. minimus* (never as much as 1% of the spring flora).[10] *Biddulphia aurita*, usually an insignificant item in the flora of the open gulf, may likewise be prominent locally in spring, if other diatoms be scarce, as off the Merrimac River on March 4, and off Yarmouth, Nova Scotia on April 13 of 1920 (Bigelow, 1926). It is, however, chiefly confined to the coastal belt, there being only three records of it in the gulf outside the 100-meter contour.[11] The Thalassiosira association also includes the arctic forms *Fragilaria oceanica*, *Navicula Vanhoeffeni* (limited to the early spring and chiefly to the eastern side of the gulf) and *Achnanthes taeniata*, which was recorded at 17 stations during April in 1934—also near the coast south of Nova Scotia in that same month of 1932 (Gran and Braarud, 1935), but at one station only in May. Being unknown in the western and southern parts of the gulf, Achnanthes probably enters the latter with the cold drift from the east.

We also have record of *Eucampia zoodiacus* at a number of the April stations in 1934, both on George's and Brown's Banks and in the northern part of the gulf off the mouth of the Bay of Fundy, a distribution seemingly characteristic, for Gran and Braarud (1935) found it frequently on the northern side of the gulf in 1932 from April to June. The accompanying table shows the relative importance of certain of these species of diatoms during the height of the Thalassiosira maximum at selected stations for late April 1934:

Species	Percent of Population					
	Off Mt. Desert Island	Off Western Nova Scotia	Off Southern Nova Scotia	Eastern Basin (3 stas.)		
Thalassiosira Nordenskioeldi	45	54.3	39.1	59	52.7	61
Th. decipiens	45	23	20.8	24	27.3	31
Th. hyalina	2	8	0.9	4	1	3.3
Achnanthes taeniata	2	5	1.4	4	5	0
Biddulphia aurita	0	0	0.2	0	0	×
Chaetoceros spp.	5	8	27.0	13	12	3.5
Rhizosolenia imbricata var. *Shrubsolei*	×	0.1	0.1	×	1	1
Total phytoplankton in millions per column	1,490	13,966	285	12,817	2,122	5,312

Coincident with the multiplication of Thalassiosira in the shoal waters, the cold water peridinian *Ceratium arctica* also appears in the eastern part of the gulf, though in small numbers and sporadically. In May 1915, for example, it ranked in abundance with *C. longipes* on German Bank, but was absent from the gulf during the rest of the year. In

[10] The maximum count recorded for Leptocylindrus by Gran and Braarud (1935) whether along the coast of Maine or in the Bay of Fundy was 8,000 per liter.

[11] Three other species of Biddulphia are also known from the gulf, *B. alternans*, *B. mobilensis*, and *B. regia*.

1920 it occurred in relative abundance along the eastern side in early March; a few individuals were recorded there at the close of the diatom flowering in early May, and it reappeared along the western coast in the following mid-winter, i.e., of 1921. Intermediate forms between *C. arctica* and *C. longipes* were also numerous in these years, but Bigelow (1926) had little difficulty in differentiating between them. In the early spring of 1934 arctica-like forms again appeared in the collection along with *C. longipes*, but the numbers of both were so small and the intergradation so complete that it was impossible to distinguish between them.[12] Bigelow (1926) believes that the distribution of *C. arctica* in the gulf suggests an outside origin, and the fact that the species has never been found in even moderate abundance except on the eastern side of the gulf north of George's Bank, and that its seasonal occurrence coincides with the maximum entrance of water through the North Channel and over the Nova Scotian banks, is in line with this idea.

Duration of the Flowering of Thalassiosira. The outbursts of Thalassiosira last for four to seven weeks (average about five weeks) in the western coastal area, where, in 1913, 1920, 1921, 1934, 1938 and 1939, the peak of production for it had passed by the middle of April. Farther eastward, however, it may continue to flower in the coastal belt until well into the summer, as happened in 1915 when *Th. Nordenskioeldi* was still flourishing near Mt. Desert Island on May 15 and again on June 11. This, however, seems to be exceptional. On the Nova Scotian side of the gulf its flowering may be as brief as two weeks, as in 1920, when it was terminated by the middle of April, or it may continue for at least four weeks, as in 1932 and 1934 when *Th. Nordenskioeldi* was at its peak during the latter half of April, but had diminished almost to the vanishing point by the last week of May. The period is about the same, i.e. about 4 weeks, off the mouth of the Bay of Fundy and on the eastern side of the basin, where in 1934 it terminated before the last week in May. The growth-period for Thalassiosira is seemingly shorter, i.e. not longer than two weeks, in the waters between Cape Sable and the eastern end of George's Bank, where it had come to a close by the end of April in 1934 and in 1920 in the interval between the end of March and the middle of April, if it flowered at all in that region in that particular year. The status of the Thalassiosira community in the western basin is discussed above (p. 208).

In the open gulf Thalassiosira declines so abruptly in abundance once its peak is passed that it falls to an insignificant rank in the flora within a few days. Near Cape Ann, for example, in 1938 (Fig. 6), when samples were taken almost daily during the early spring, Thalassiosira formed about 93% of the total phytoplankton on March 30, but had entirely disappeared by April 3, similar conditions obtaining in 1939. Indications based on cruises at two to four week intervals in 1920 and 1934, combined with the data for other years, are that the genus is eclipsed with equal rapidity elsewhere (Table IV), outside the Bay of Fundy (p. 230).

Thalassiosira Nordenskioeldi is a cold water species, growing best at temperatures not higher than 5° C., the shrinkage in its numbers after its peak is passed being generally accredited to the warming of the surface layers. Its distribution in the gulf proper in the spring of 1934, as well as in the Bay of Fundy in 1932 (Gran and Braarud, 1935) is consonant with this, except where it may be subject to other influences, as in the western side of the gulf where it was no longer dominant after mid-April, and on the coastal banks south

[12] The two were combined as *C. longipes* in the preliminary report (Lillick, 1938).

of Cape Sable, whence it had disappeared by the end of May, though the surface temperatures still continued lower than 5° C.

Vernal Flowering of Chaetoceros. As the flowering of Thalassiosira declines, the diatom genus Chaetoceros tends to take its place over the gulf generally (Table IV). Appearing in the coastal waters by the end of January or early February, Chaetoceras awaits, for its rapid multiplication, the time when the surface waters warm above 5–6° C. From this date on, however, it enters upon a period of expansion as rapid and nearly as intense as the outburst of Thalassiosira which precedes it, ordinarily reaching its maximum about the time Thalassiosira falls to its minimum. Although the data for 1920 ostensibly showed Chaetoceros as at its peak at about the same date as Thalassiosira, i.e., in the early part of April, other records make it more likely that it was then in process of replacing Thalassiosira, and that the collections of 1920 had missed the earlier stages in the alternative development. In the vicinity of Gloucester, Massachusetts, in 1938 this alternation in dominance took place within the period of a few days (Fig. 6), as it did again in 1939. Nor is it probable that the interval involved exceeds a week or ten days, in any part of the open gulf.[13]

Regional expansion of the Chaetoceros flowering closely parallels that of Thalassiosira (Table IV), its development being earliest in the western coastal belt south of Cape Elizabeth, and on the western part of George's Bank; somewhat later off southern Nova Scotia. In 1938 and 1939 Chaetoceros was dominant off Gloucester by the end of March; not, however, in the western coastal belt until after the middle of April in either 1920 or 1934. In some years Chaetoceros becomes dominant equally early in the season on the western side of the deep basin, as in 1920 and 1934—probably also in 1932—though in other years (e.g., 1915) this stage in the cycle may be delayed there until early May.

Rich flowerings of Chaetoceros are equally to be expected by the middle or end of April on George's Bank. In 1913, for example, the entire northern half of the latter supported an abundant Chaetoceros flora during the latter half of the month. In 1920 *Ch. socialis* dominated on the southwestern part of the bank both in late February and again in May (the only record of this species in abundance in the gulf at any season), but with other members of the genus dominant on the southeastern part in April (Bigelow, 1926, p. 422). Again in 1934 Chaetoceros had displaced Thalassiosira over the western half of the bank by about the middle of April, and on the eastern end by the end of the month. But the irregularity of these occurrences makes it doubtful whether rich flowerings of Chaetoceros normally develop simultaneously over the bank as a whole at any time during the year. Chaetoceros dominated the phytoplankton equally early west of Nova Scotia, and between Cape Sable and the northeastern tip of George's Bank in 1920, i.e., by mid-April. In 1934, however, the coastal banks on this side of the gulf still supported a monotonous flora of Thalassiosira as late as the last week of April, though Thalassiosira and Chaetoceros were in roughly equal abundance south from Cape Sable. A Chaetoceros plankton does not usually develop in the northern coastal belt (i.e., east of Portland) until the latter part of May. In 1932, for example, Chaetoceros was about as numerous as Thalassiosira from Penobscot Bay to the Bay of Fundy by the end of that month (Gran and Braarud, 1935), while in 1915, the genus was first found dominant near Mt. Desert Island on June 11, following the prolonged flowering of Thalassiosira already noted (p. 211) for that particular year.

It is not certain whether Chaetoceros flowers actively on the eastern side of the basin

[13] See, however, Davidson's (1934) graphs for the Bay of Fundy; also p. 230.

every year, for though it dominated the rich plankton there during the first half of May 1915, it was not numerically important in that general region in late April of 1934, though well represented among the Thalassiosira community (Chaetoceros, about 5%, Fig. 4). If Chaetoceros flowered at all in this particular area in 1934, it must have done so in mid-May, for it was only sparsely represented there in late April (Fig. 4), and diatoms of any sort were very scarce there by the end of May.

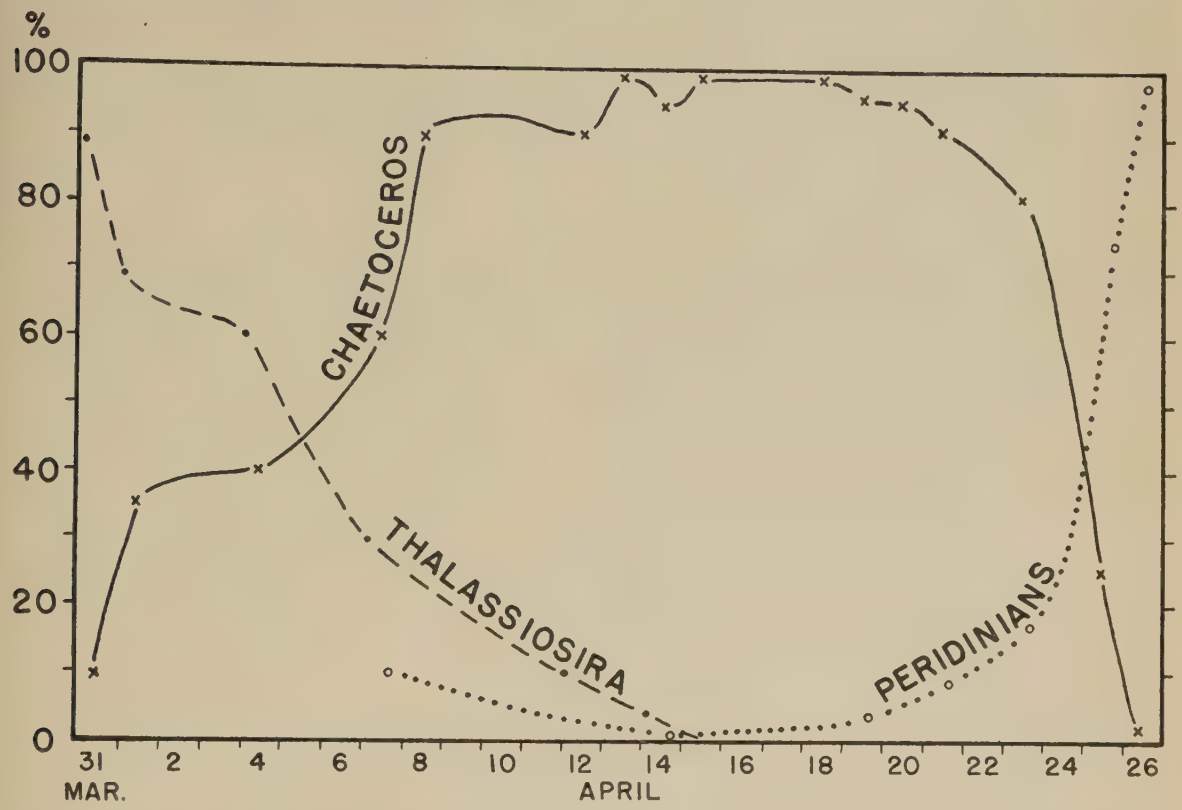

Fig. 6. Percentages of Thalassiosira, of Chaetoceros, and of Peridinians in the total phytoplankton off Gloucester, Massachusetts, March–April 1938.

At their respective peaks of abundance (Fig. 4) Chaetoceros ranks second to Thalassiosira in numerical strength, the maximum numbers of cells per column so far recorded for the two in the spring of 1934 being as follows, at localities:

Locality	Chaetoceros	Thalassiosira
Off Seguin Island	1,030,000,000	234,000,000
Mouth of Bay of Fundy	490,000,000	7,430,000,000
Eastern Basin	1,229,000,000	11,900,000,000
Eastern Basin	427,000,000	7,260,000,000
Eastern Basin	193,000,000	5,066,000,000
Southwest edge of Nova Scotian coastal bank	24,000,000	1,165,000,000
Eastern Basin	66,000,000	424,000,000
Brown's Bank	57,000,000	88,000,000
North Channel	95,000,000	131,000,000
Eastern George's Bank	53,000,000	87,000,000

Composition of the Chaetoceros Flora. At the height of its development the Chaetoceros flora includes a greater number of species than does the Thalassiosira flora, as many as 30 members of Chaetoceros alone often occurring together, though the composition of the community is relatively uniform over the gulf as a whole. In six years out of the ten of record *Ch. debilis* has dominated, sometimes even forming nearly a "closed stand" as it did off Gloucester in April 1939. In other years, as in 1938, *Ch. constrictus* may outnumber *Ch. debilis*, the two making up 90–95% and 0.1–5% of the flora respectively. *Chaetoceros compressus*, *Ch.* (*diadema*) *subsecundus* and *Ch. decipiens* have also been found dominant locally along the western and northern coasts in still other years, e.g., 1920, 1934, 1938 and 1939; and *Ch. densus* in 1915. A typical Chaetoceros association for late April (as in 1934) includes the following species, most of which do not appear in the gulf until February or March:

Species	Percent of Flora
Chaetoceros affinis	2.0
Ch. atlanticus	0.5
Ch. borealis *	0.3
Ch. compressus	7.0
Ch. constrictus	3 0
Ch. convolutus	0.5
Ch. crinitis	
Ch. debilis	65.0
Ch. decipiens	1.0
Ch. densus	
Ch. didymus	2.0
Ch. furcellatus	0.3
Ch. laciniosus	2.0
Ch. radicans	2.0
Ch. scolopendra	
Ch. socialis	2.0
Ch. subsecundus	2.0
Ch. teres	1.0

* *Chaetoceros borealis* and *Ch. convolutus* so intergrade that in all probability they should finally be combined under the older name *Ch. borealis* Bailey (1854), as Gran (1904) and Føyn (1929) have already argued.

The particular species of Chaetoceros that sometimes appear at the close of winter (p. 203) (*Ch. atlanticus*, *Ch. convolutus*, *Ch. borealis*, *Ch. decipiens*) do not usually attain numerical importance in spring though persisting as minor elements of the flora. This group may, however, dominate throughout the spring in one or another part of the basin in years when a pronounced peak of Thalassiosira fails to develop there, sometimes augmented by *Ch. densus*, *Ch. debilis* or related species. In 1915, for example, *Ch. densus* occupied that rôle in the very abundant plankton in the western basin off Cape Ann through May. Again in 1920 this same group of species occupied much of the northwestern part of George's Bank through March, April and early May, though with *Ch. socialis* dominant on the southwestern portion of the bank. This group was not detected at all in January or March of 1934, but *Ch. convolutus*, accompanied by *Ch. atlanticus*, *Ch. decipiens* and *Ch.*

borealis (species present over the entire gulf at the time, though insignificant elsewhere in relative abundance), dominated the scanty flora in the northern part of the western basin late that April (Fig. 4). The limits of this flora were sharp, especially in the north, and it persisted in this same general region until late in May, though with its boundaries shifting a few miles inshore (cf. Fig. 5 with Fig. 7), but it had disappeared by late June. No satisfactory explanation for its temporary development is suggested.

Of the 30 odd species of Chaetoceros *Ch. decipiens* is the most persistent in small numbers throughout the year, though it never occurs in great abundance within the gulf at any season (for maximum count, see p. 221).

Duration of the Chaetoceros Flowering. The duration of the Chaetoceros flowering varies as widely as does that of Thalassiosira (Table IV). In shoal water near Cape Ann in 1938 the genus dominated the surface layers for three weeks only, i.e., until the last

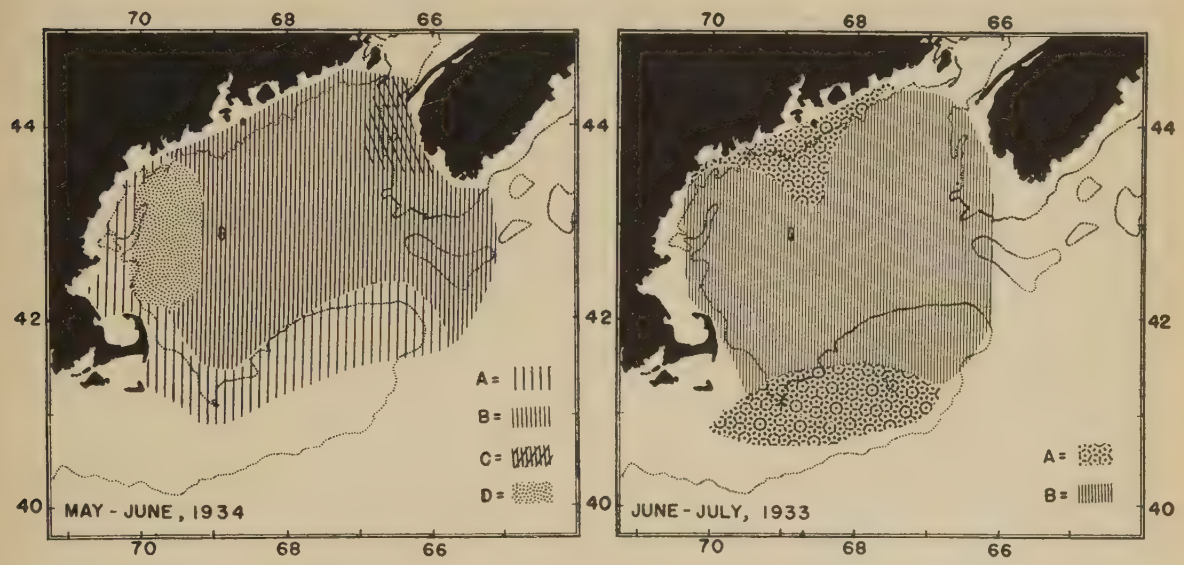

FIG. 7. Distribution of phytoplankton communities in the Gulf of Maine. Left: Late May–early June 1934; *A*, Chaetoceros; *B*, Peridinians; *C*, Chaetoceros and peridinians; *D*, *Chaetoceros convolutus*. Right: Late June–early July 1933; *A*, Chaetoceros and neritic diatoms; *B*, Peridinians and coccoliths.

week of April; and for about six weeks between Cape Ann and Cape Elizabeth in 1915 and 1920, to terminate by the end of May. From Cape Ann southward to and including George's Bank Chaetoceros may flourish for perhaps four weeks, disappearing during the first days of May as in 1913, or by the end of the month as in 1915 and 1920. In other years, however, the Chaetoceros community may persist in moderate abundance in the western coastal belt throughout the early summer, as happened in 1914 and 1934 (Fig. 7). In the shoaler waters off southern and western Nova Scotia Chaetoceros flowered in abundance until the first part of May in one year (1915), and until the middle or end of the month in others (1932, 1934), i.e., for about four weeks. Its flowerings have been found to last from four to six weeks or even longer, in the northern coastal belt and off the mouth of the Bay of Fundy, to diminish late in May in an early year (e.g., 1932), but not until mid- or late June in a late one, as in 1915. In the western basin the period lasts 5–6 weeks,

i.e., until late May (1920, 1934) or early June (1915), and about equally long in the eastern basin to judge from the fact that the waters there were free from diatoms of any sort by the end of May or by early June in each of those years.

The fact that in 1938 the percentage of Chaetoceros fell in the course of the five day period between April 22 and 26 from 98% of the phytoplankton to less than 1% illustrates the suddenness with which its numbers may decline (Fig. 6) once its peak of abundance is passed. Sundry observations make it likely that this applies over the gulf in general. Chaetoceros persisted, however, at scattered points along the western coastal regions in

TABLE IV

SEASONAL CYCLE OF THALASSIOSIRA AND CHAETOCEROS

Area	Thalassiosira			Chaetoceros		
	Initial Flowering	Duration in Weeks	Termination	Initial Flowering	Duration in Weeks	Termination
Boston Harbor and Cape Elizabeth	Mid-March	4–7	Early to mid-April	Mid-April	ca. 3–6	Mid–late May
Massachusetts and Cape Cod Bays	Early April	2–4	Mid-late April	Mid-end of April	3–4	First–last of May
Western George's Bank	ca. 20th of March	2–3	Mid-April	Mid-April	3–4	Mid-May
West Basin	End of March	ca. 2	ca. mid-April	ca. mid-April or early May	ca. 5	Late May or June
Nova Scotia Shoal waters	Early April	2–3	ca. early May	Early May	ca. 4	Late May
Eastern George's Bank	Early April	2–3	Late April	Late April	ca. 4	End of May
Cape Elizabeth across to the Bay of Fundy	ca. April 10th	2–6 or indefinitely	ca. late May	Late May	4–6	Mid–end of June or August
East Basin	Mid-April	3–4	ca. mid-May?	Mid-May	—	—

scant numbers throughout the summers of 1913, 1914 and 1915. *Chaetoceros* (*criophilum*) *convolutus* was in fact relatively abundant off Penobscot Bay on August 14, 1914.

Phaeocystis. In 1920 Bigelow found the unicellular alga Phaeocystis practically monopolizing the surface waters in the southern part of Massachusetts Bay and in Cape Cod Bay during the latter half of April when it rivalled in its abundance the preceding peak for diatoms; it was also scattered sparsely over the western basin at the time. But this flowering was so brief that it was found neither three weeks previously nor two weeks later. In as much as we have no other record of Phaeocystis it is an open question whether its

occurrence in 1920 was exceptional, or whether it flowers annually in the gulf, but so briefly and so sporadically that the other surveys have missed it.

Halosphaera. The spring is also the season of maximum frequency for the unicellular green alga *Halosphaera viridis*, which was recorded—always in small numbers—at many stations in March of 1915, and in that and the two succeeding months of 1920. It was not detected at all in 1933–1934; hence the reader is referred to Bigelow (1926, p. 459) for a discussion of its status in the gulf.

Summer Florae

Early Summer Flora. On George's Bank diatoms may continue to dominate the flora throughout the summer, though sporadically both as to dominant species and as to numerical distribution. In 1934 the bank as a whole supported a Chaetoceros community in May and June (Fig. 7), but in other summers the diatom florae have been limited on the banks to isolated areas, with sparse peridinian florae elsewhere. In 1915 and 1920, for example, communities of Chaetoceros were encountered on the southwest corner of the bank, whereas in 1933 diatoms, chiefly Chaetoceros accompanied by Thalassiosira, *Guinardia flaccida* and others, as well as by the coccolith *Pontosphaera Huxleyi*, occupied the western half (Fig. 7). *Guinardia flaccida* flowered on the western end of the bank in early July of 1913, with lesser numbers of *Eucampia zoodiacus* (Bigelow, 1926, Fig. 123), the latter a spring and summer [14] species chiefly limited to the shoaler parts of the gulf. Late in July of 1916 (Bigelow, 1926, Fig. 124) this same general region was dominated by Rhizosolenia and by the oceanic species *Thalassiothrix longissima*, a species which is probably an immigrant in the gulf, though there are scattered records of its presence inshore as well as offshore between March and October (Fritz, 1921; Bigelow, 1926; Gran and Braarud, 1935). Guinardia was flowering in July, 1914 on the northeast part of the bank, where in the same month of 1933, *Pontosphaera Huxleyi* far outnumbered the moderately abundant diatoms, chief among which were *Detonula confervacea* and *G. flaccida* (Braarud, 1934). The fairly rich phytoplankton in this same area recorded in late June and early July of 1934 was chiefly *Thalassiosira Nordenskioeldi*, *Thalassionema nitzschioides*, *Melosira sulcata*, *Nitzschia longissima*, *Peridinium conicum*, *P. Granii* and *P. simplex*, with small flagellates. Evidently, then, the diatom florae on the banks may be dominated in summer by any one of a number of species, most often perhaps by *Guinardia flaccida*.

In some years (e.g., 1912, 1914, 1915, 1933) a stock of diatoms sufficient to dominate the diminished flora—but in this case chiefly Chaetoceros—accompanied by Peridinians (especially Ceratium) in smaller numbers—also persists in the western and northern coastal belt throughout the summer months; especially is this likely to be the case in the easternmost sector of this belt near Mt. Desert Island and in the Bay of Fundy.

Typically this flora includes the following species:

Chaetoceros atlanticus	(boreal oceanic)
Ch. compressus	(boreal neritic)
Ch. cinctus	(temperate neritic)
Ch. constrictus	(temperate neritic)
Ch. debilis	(boreal neritic)

[14] Gran and Braarud's (1935) new species, *E. recta*, was not detected in 1933–1934.

Ch. decipiens	(boreal oceanic)
Ch. didymus	(temperate neritic)
Ch. furcellatus	(arctic neritic)
Coscinodiscus centralis	(boreal oceanic)
Guinardia flaccida	(temperate neritic)
Leptocylindrus danicus	(boreal neritic)
Rhizosolenia fragilissima	(boreal neritic)
Rh. hebatata var. *semispina*	(boreal oceanic)
Rh. imbricata var. *Shrubsolei*	(temperate oceanic)
Thalassionema nitzschioides	(boreal neritic)
Thalassiosira decipiens	(boreal neritic)
Th. Nordenskioeldi	(boreal neritic)
Thalassiothrix longissima	(boreal oceanic)

In other years, when the vernal warming of the surface waters is accompanied by an eclipse of the Chaetoceros flora (as described above), leaving the gulf as a whole nearly barren of diatoms, the latter are succeeded by a sparse community of peridinians, a situation developing earliest near Cape Ann and southward to Massachusetts Bay, but extending northward throughout the coastal area within a few days. In 1938, for example, peridinians which were only 4% of the flora near the Cape on April 19th soon dominated so strongly over the few remaining diatoms that they constituted 99% by the 26th of the month (Fig. 6), and in 1915 they dominated in Massachusetts Bay by the first week of May. Dinophycean dominance was similarly established south of Mt. Desert Island by the end of April in 1932, throughout the entire western and northwestern coastal waters by mid-June in 1934 and by early July 1933 or earlier (Fig. 7).

In the offshore basins also the waters were practically clear of diatoms by the end of May in 1934, their place having been taken by a very scant flora of peridinians, and although in 1915 this development did not involve the basin as a whole until late in June, this was found to be a tardy year in other respects as well.

The situation is seemingly more complex in the eastern coastal belt. Here in 1915 the diatoms had practically disappeared, and peridinians had succeeded them by early May, but they reappeared then in small numbers among the more numerous peridinians; in the summer likewise over Brown's and German Bank and in the North Channel (Bigelow, 1917; 1926). On the other hand it seems likely that the weak growth of Chaetoceros which mingled with the peridinian population west of Nova Scotia at the end of May in 1934 (Fig. 7) was evidence of a stage in the disappearance of the diatoms, rather than of a tendency for these to persist in abundance into the summer, since peridinians had by then monopolized the waters southward from Cape Sable.

The Dinophycean flora of late spring and early summer is dominated by *Ceratium longipes*, *C. tripos* and *C. bucephalum*, with considerable numbers also of *C. Fusus* and *C. lineatum*. Often the entire flora consists of little but this genus; however, Ceratium is usually accompanied by *Peridinium depressum*, *P. conicum*, *P. crassipes* and other species of that genus, as well as by Dinophysis and Exuviella. The latter reaches its maximum abundance in May and June (up to about 1,000 cells per liter, Gran and Braarud, 1935), *E. baltica* and *E. marina* being the most important species. Mixed with the peridinians

are also a scattering of temperate species of diatoms, among them various species of Chaetoceros, *Rhizosolenia hebatata* var. *semispina*, *Rh. fragilissima*, *Rh. imbricata* var. *Shrubsolei* and *Thalassiothrix longissima* (Fig. 8). Water bottle samples for the summers of 1932, 1933 and 1934 [15] have also shown that Coccolithophoridaceae, especially *Pontosphaera Huxleyi*, may also be numerically important in the flora at this season. Offshore and inshore stations are in agreement in all this, the chief regional differences in this respect being that tychopelagic diatoms appear in greater numbers at the former; whereas Coccolithophorids frequently dominate the summer flora offshore (Fig. 8), which rarely, if ever, happens inshore in so far as our knowledge of this area goes.

The development of summer dominance by peridinians results in part from the impoverishment of diatoms, but in part also from multiplication by the peridinian species that are present during the vernal outburst of diatoms, combined with the appearance of additional species as well, the cyclic development in the gulf of the several species of Ceratium being especially interesting in this connection. Of the seven species and numerous varieties of that genus which occur there, *C. tripos*, *C. longipes*, and *C. Fusus* are the most abundant; the latter is rather generally distributed throughout the year; the other two, however, show decided mutual fluctuations which have already been discussed in detail by Bigelow (1926). Briefly the situation is as follows: both species are present throughout the year, but *C. tripos* dominates the offshore plankton during the winter, while *C. longipes* is very scarce. Both species are at their minimum during the spring flowerings of diatoms —as are all other peridinians. *Ceratium tripos* also continues scarce after the diatoms diminish in numbers, but *C. longipes* then multiples to its maximum in July, when the gulf as a whole (but with the exceptions noted above) supports the most abundant Ceratium plankton of the year. During August *C. longipes* declines in amount, but *C. tripos* multiplies, with the result that within two or three weeks the relative importance of the two species has been reversed. This reversal from dominance by *C. longipes* to dominance by *C. tripos* takes place earliest over the southern and western half of the basin, following northward and eastward, until it finally involves the northern coastal belt from Casco Bay to the Bay of Fundy by September or early October (Bigelow, 1926, Fig. 110). Further evidence that this sequence is fairly constant, although with local exceptions, is provided by the data for more recent years; thus, while both of these species were present in small numbers only (though widespread) in December, January and March of 1933–1934, *C. longipes* greatly outnumbered *C. tripos* by June in most parts of the gulf. A similar situation also developed within the space of a few days near Cape Ann in late April of both 1938 and 1939. By August of 1938, however, *C. tripos* had again become the dominant peridinian in the western side of the gulf (the only region examined in that summer); whereas by September (of 1933) it and *C. longipes* were both present in roughly equal numbers.

The mutual relationship of these two species seems essentially the same on George's Bank also, for *C. longipes* was the more abundant member of the pair there in late May, but *C. tripos* definitely so in June of 1934, in July of 1933 and in August of 1932, but with the two about equal in September (1933). Both were so scarce (20–40 per liter) during the late autumn, winter and early spring of 1933–1934 that sometimes the one was recorded

[15] Records for previous summers were based on catches with tow nets which do not sample vegetable cells as small as Pontosphaera.

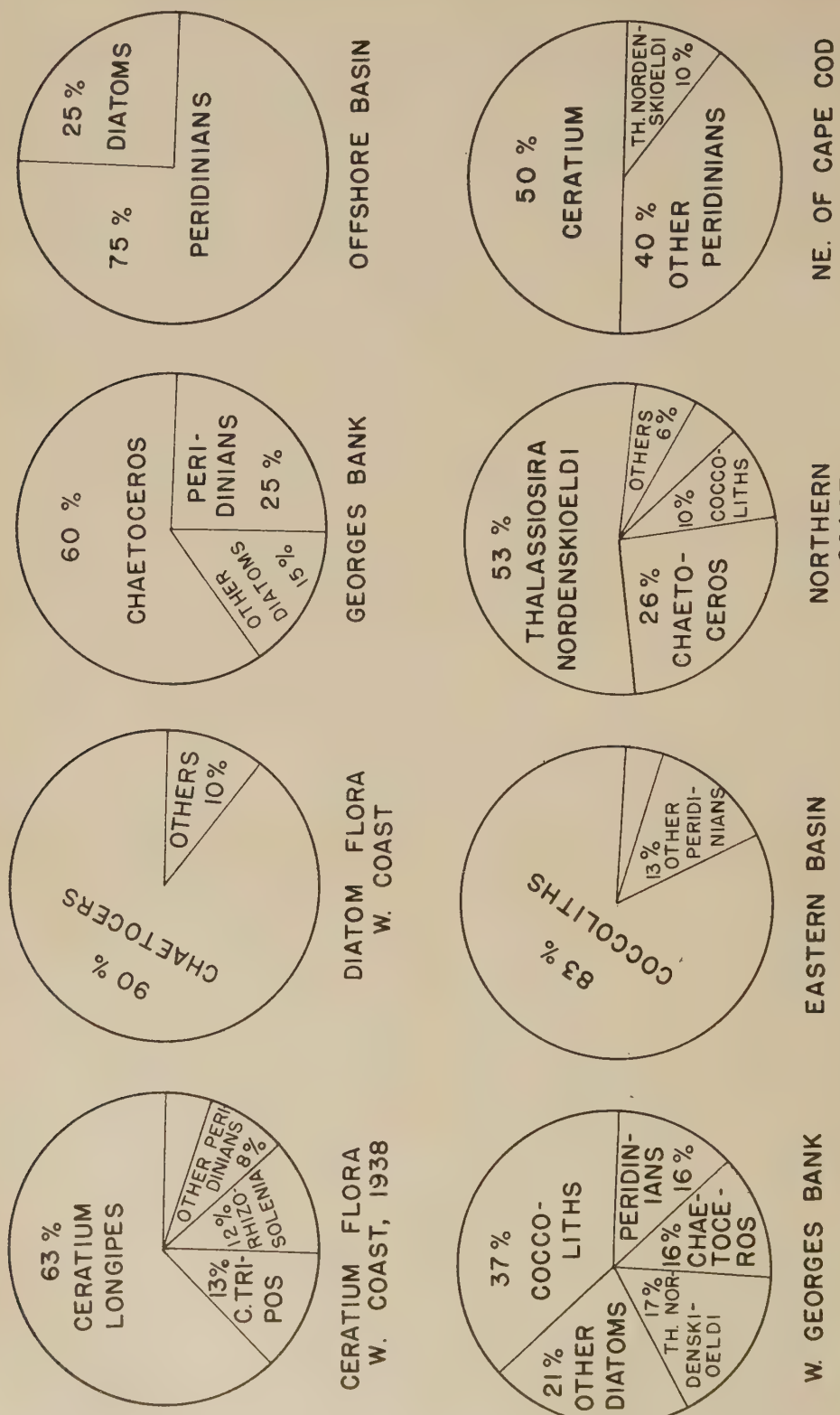

FIG. 8. Percentage composition of the phytoplankton at representative localities in the Gulf of Maine, late May–early June 1934 (above), and late June–early July 1933 and 1934 (below).

(in October, December, January, *C. tripos*), sometimes the other (*C. longipes* in March), and sometimes neither (April, 1934). Gran and Braarud (1935) who found *C. tripos* less abundant than Bigelow's (1926) records led them to anticipate, but *C. bucephalum* more so, suggested (on the basis of one of Bigelow's (1926) microphotographs) that he might have confused the two species, but the evidence for 1933–1934 and for 1936 tends to substantiate Bigelow's conclusion that *C. tripos* is usually much more abundant than *C. bucephalum*, for when the latter was detected at all, it was always recorded as "scarce." It is often difficult, however, to distinguish between these two members of this proverbially variable genus.

Late Summer Florae

The chief alteration in the flora during the late summer or early autumn is in connection with the second diatom flowerings, for which Chaetoceros, Rhizosolenia or Sceletonema are chiefly responsible in one part of the gulf or another. On the northern coastal belt, as exemplified by Penobscot and Frenchman's Bays near Mt. Desert Island, Chaetoceros predominates the more often than Rhizosolenia in the late flowerings, with *Ch. debilis*, *Ch. decipiens*, *Ch. compressus*, and *Ch. laciniosis* as the most abundant species (Burkholder, 1933). Gran and Braarud (1935) also found Chaetoceros in numbers as high as 300,000 cells per liter near Mt. Desert Island on August 14, 1932 (including 3,600 of *Ch. decipiens*, the highest count yet recorded for that species in the gulf), and somewhat less abundant at neighboring stations after a period of diatom scarcity. The representative species of Rhizosolenia that develop in greatest abundance inshore in late summer are *Rh. setigera*, *Rh. imbricata* var. *Shrubsolei*, and *Rh. hebatata* var. *semispina*. It is chiefly this genus which is responsible for the second flowering that occurs farther outside along the northern coastal belt and over George's Bank (Fig. 9). The late summer is, in fact, the only season when

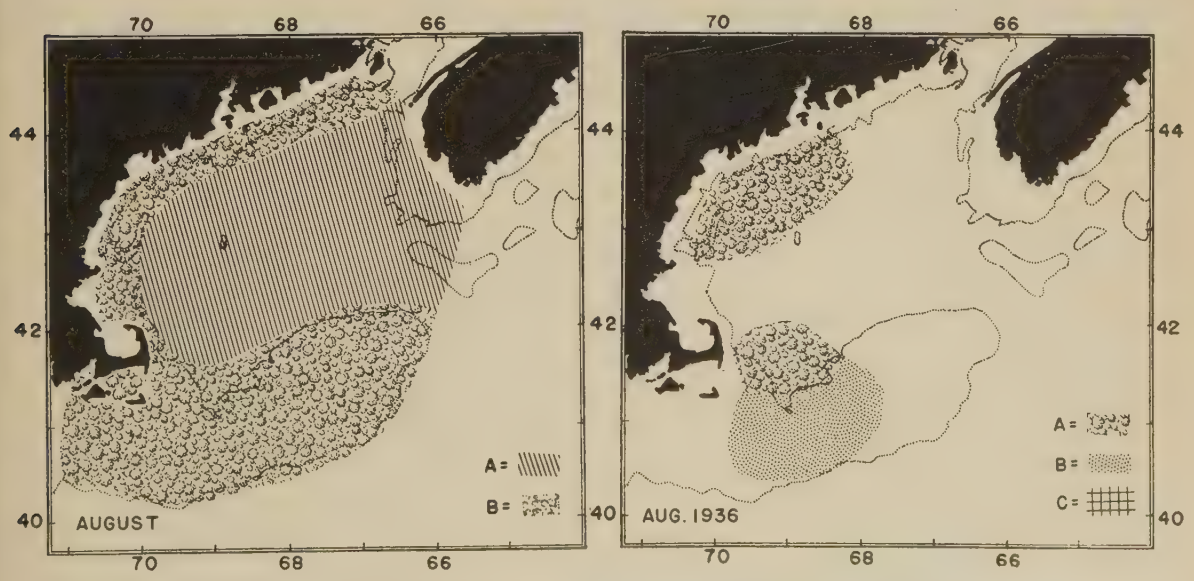

Fig. 9. Distribution of phytoplankton communities in the Gulf of Maine. Left: August, *A*, Ceratium plankton; *B*, Extent of diatom flowering. Right: August 1936, *A*, *Rhizosolenia alata; B*, *Rh. styliformis; C*, *Rh. calcar-avis* and *Sceletonema costatum*.

this genus multiplies to great abundance (see, however, p. 203), though it occurs widespread in the gulf in small numbers throughout the year. The leading members of the late summer florae for these areas are *Rh. alata*, which usually rank first, *Rh. styliformis*, *Rh. imbricata* var. *Shrubsolei*, *Rh. setigera* and *Rh. hebatata* var. *semispina*. *Rh. alata* is on the whole the most important member of the genus in the gulf, where, by present indications it has two flowerings, one of low intensity at the close of the winter (p. 204), and a second in August of great intensity but irregular in distribution. Instances are: its dominance in the moderately abundant plankton of the outer Massachusetts Bay in August, 1922; off Mt. Desert Island in July, 1915; and its presence in abundance in the deep water a few miles to the north of the bank on July 8, 1913; contrasted with its presence in small numbers only on George's Bank in July of 1914 and 1916 (Bigelow, 1926, p. 447). It was also dominant on the eastern part of George's Bank (maximum frequency, 50,000 cells per liter), the most abundant diatom (though subordinate to Ceratium) in the neighboring basin, and common in the northern part of the gulf and in the Bay of Fundy (up to 6,000 per liter) in August of 1932 (Gran, 1933; Gran and Braarud, 1935). Although it was very scarce at two stations on the eastern side of the gulf in July 1933 (Braarud, 1934), it was again so abundant at the six stations on the western side of the gulf in August of 1936 that it colored the water (Fig. 9 —no counts of cells available). However, it has never been found in any number during the summer in the waters off western Nova Scotia. These records are enough to show that *Rh. alata* may be expected to flower yearly in the northern and western coastal belts, on George's Bank and to some extent over the deep basins in August (or even in July). It is, in fact, at this season that it reaches its greatest development in these parts of the gulf.

Rh. hebatata var. *semispina* was the species dominant south of Marthas Vineyard in August (of 1914), where it formed the bulk of the catch (Bigelow, 1926, p. 443, Fig. 125). It was, however, scarce or absent from these localities in other summers, as in 1914, 1916 (Bigelow, 1926) and 1933. Although rather generally distributed farther north in the gulf in July of that year or in September, it was nowhere dominant there, nor did Gran and Braarud (1935) find it in any numbers in August of 1932, whether in the open gulf or in the Bay of Fundy, though it occurred there regularly from April (maximum, 300 cells per liter) to September and was fairly abundant near Cape Ann in late April 1938. Late summer or early autumn flowerings of this species thus appear to be limited to the southern side of the gulf, and are sporadic even there.

Rhizosolenia imbricata var. *Shrubsolei*, present in the Gulf of Maine from February through October and even as late as December in the Bay of Fundy, was similarly found in moderate numbers (ca. 200 per liter) over George's Bank in July of 1933, also in great abundance in Nantucket Sound in 1915, and in late August of 1936—when it was only slightly less numerous there than was *Rh. calcar-avis*, a species the northward extension of which appears to be limited by Cape Cod. *Rhizosolenia styliformis* is far more important on George's Bank and Nantucket Shoals, where it has been repeatedly recorded in large numbers during July and August (Fig. 76), than it is in the inner parts of the gulf, as Bigelow (1926) has pointed out. This species is typically oceanic; Bigelow accounts for its distribution in the gulf as being conditioned by the entrance of oceanic water.

Guinardia flaccida may likewise be an important component of the late summer flowering, though generally less so than Rhizosolenia, occurring characteristically in very localized but dense aggregations, instances of which have been recorded at various points close

to shore in the western coastal belt as well as on the southern banks. Thus Bigelow reported a dense flowering of it over the western part of George's Bank in July 1914, and Gran (1933) and Braarud (1934) found it an important member of the July and August flora on the eastern part of the bank in 1932 and 1933. It also appeared, though usually subordinate to Rhizosolenia, in every region investigated in August of 1933 and 1936; and in September (of 1933) when 100,000 cells per liter were recorded near Seguin Island; Gran and Braarud (1935) likewise recorded it from Passamoquoddy Bay in September, but in small numbers only (maximum, 460 cells per liter). This regularity of occurrence in late summer and early autumn, contrasted with the record of it at one station only in January and in June, shows that Guinardia is distinctly a warm water form in the gulf.

Sceletonema costatum, a species of major importance in the early spring diatom maximum in the waters of northern Europe, develops in considerable abundance in the Gulf of Maine or in the Bay of Fundy only in late summer, when it may multiply to 700,000 cells per liter or more. Even then, however, there is no record of it in the gulf in such numbers as in European seas, where on occasion, there may be several million of its cells per liter. Its flowerings in the gulf are closely confined to the vicinity of the coast. Thus, Gran and Braarud (1935) found it far more abundant (ca. 500,000 cells per liter) close to shore near Mt. Desert Island in August of 1932 than was Rhizosolenia (ca. 1,000 cells per liter); also in numbers as high as 39,000 cells per liter along the western Nova Scotian coast. The same species was abundant on the western part of George's Bank on July 9, 1913, dominant in Nantucket Sound in August of 1936, and responsible for the second flowering of diatoms that developed in Massachusetts Bay in September of 1915 (Bigelow, 1926, p. 394), but for which no counts are available. On the other hand Gran (1933) found only a few scattered chains of it off shore either on George's Bank or in the basin to the northward in August of 1932, and it was not detected at all in the summer of 1916 (Bigelow, 1926), showing that its aestival flowerings are not as regularly annual or as widespread, even within the zone of its most characteristic distribution, as are those of the vernal diatoms. Sceletonema is made further interesting by the probability that it differs from most others in having two flowerings a year in the gulf, the one in late summer and early autumn, the other—far less productive—in winter (p. 204).

Gran and Braarud's (1935) record within the Bay of Fundy of 100,000 cells per liter of *Thalassionema nitzschioides* suggests that that species may also flower twice yearly here but most intensely in summer, since the only large count for it in the open gulf was for March (p. 204). *Nitzschia seriata*, present from late January to October, also has its maximum in July or August. It is most plentiful in the peripheral belt of the gulf, but never sufficiently so to come within the "dominant" category, the largest recorded count for it in the gulf being about 8,000 cells per liter. *N. Closterium*, with a similar seasonal distribution, but usually very scarce, was found abundant on one occasion in August, 1936 growing on the walls of Rhizosolenia.[16] *Thalassiothrix longissima* also calls for mention in the summer-autumn group, because it dominated a rich plankton on western George's Bank in late July of 1916, but we have few other records of its occurrence in the gulf.

Finally, to emphasize the sporadic nature of the late summer flowerings of diatoms as contrasted with the vernal, we may instance the case of *Asterionella japonica*. In August of

[16] For the seasonal occurrence of the other species of Nitzschia in the gulf, *N. delicatissima* and *N. longissima*, see Table I, p. 196.

1912—a summer when diatoms as a whole were more than usually abundant—this species was widely distributed in small numbers along shore from Cape Elizabeth to western Nova Scotia, and in such abundance between Grand Manan Channel and Sequin Island that "the appearance of the water was noticeably soupy" (Bigelow, 1914, p. 133), with "such a sudden transition to clear water with very little plankton" near Seguin Island "that the change was plainly visible from the deck of the *Grampus*" (Bigelow, 1926, p. 431). Subsequent records of Asterionella in the open gulf are confined to small numbers in the offing of Mt. Desert Island in August, 1930 (Burkholder, 1933) and to the northern part (chiefly inshore) in August of 1932 (Gran and Braarud, 1935). It is more common in the Fundian region occurring in small numbers near St. Andrews between April and December, and more numerously in the open bay, with a distribution center near Grand Manan Island where (in 1932) it had a distinct maximum in August, though always subordinate to other diatoms (Gran and Braarud, 1935). This distribution suggests that the presence of Asterionella in such unusual abundance in the northern gulf in 1912 may have been due to a greater Fundian influence in that summer than is usual, and this hypothesis is supported by the fact that the drift of cold surface water from the bay was also more strongly developed along the northern shore of the gulf in that summer than in those of 1915, 1923 or 1925 (cf. Bigelow, 1927, Fig. 47).

Other diatom species that are present in small quantity in late summer and some of which are limited to that season, are listed in Table I.

During the second diatom flowering the peridinians as a rule play a very insignificant rôle in the flora because of the great numbers of diatoms, though the same peridinian species which are present earlier in the summer persist in undiminished quantity and with additional species as the summer progresses (Table II).

The bowl of the gulf outside the 100-meter line is only slightly affected by the second flowering of diatoms, and the chief alteration in the percentual composition of the phytoplankton which takes place there from early to mid- and late summer is that *Pontosphaera Huxleyi* (the only coccolith which is of numerical importance in the gulf) may so increase in abundance as to raise its numbers far above those of the peridinians locally, as was the case at two stations on the northwestern part of the gulf in August, 1932 (Gran and Braarud, 1935), on the eastern part of George's Bank, July 16–18, 1933 (Braarud, 1934), and in the southeastern part of the basin on that same cruise,[17] as well as in the preceding August (Gran, 1933, Table I). Coccoliths, in fact, are at their maximum abundance at that season. Such extreme development of Pontosphaera appears, however, to be restricted to rather definitely circumscribed centers, for other mid- and late summer stations have yielded larger numbers of peridinians than of coccoliths.[18]

Apart from Pontosphaera, peridinians continue to dominate the bowl of the gulf throughout the late summer and early autumn, Ceratium being most conspicuous in all regions, accompanied by lesser numbers of Peridinium and of the smaller Dinophyceae and only occasional diatoms (Fig. 10), except as these may extend out into the deep basins from

[17] The latter was the maximum count so far recorded for Pontosphaera in the gulf, 308,000 per liter at the level of greatest abundance (Braarud, 1934, Table 1).

[18] The methods used to concentrate the material of 1933–1934 were such as to distort most members of this group beyond specific recognition. For a further account of these forms, see Gran and Braarud (1935).

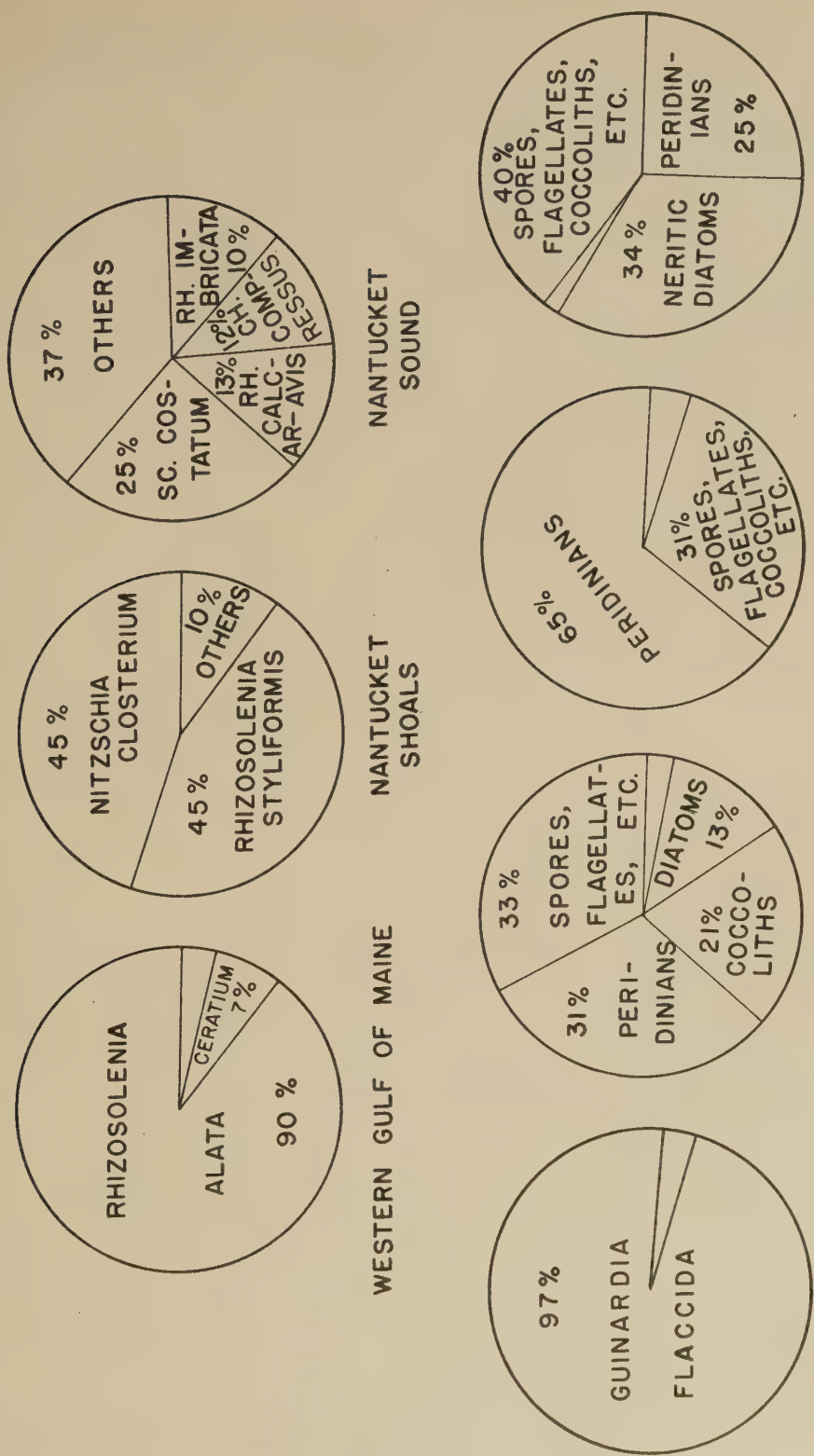

FIG. 10. Percentage composition of the phytoplankton at representive localities in the Gulf of Maine, August 1936 (above) and September 1933 (below).

the western coastal belt and from George's Bank. The Rhizosolenia flowering of August 1936, for example, spread well out into the western part of the basin (Fig. 9), where *Rhizosolenia alata* formed more than 90% of the population, with other species of that genus, *Guinardia flaccida* and Chaetoceros present in small numbers, in combination with the assemblage of *Ceratium tripos, C. Fusus, C. longipes* and Peridinium that is usual for the season.

August–September is the season of maximal abundance for Dinophysis which is found regularly through late spring, summer and autumn, but at all times in small numbers. Of the 7 or 8 species recorded *D. acuminata* and *D. norvegica* are the most prominant, Gran and Braarud (1935) having recorded up to 1,100 per liter of the former and 1,560 of the latter. The largest counts for Goniaulax [19] in the open gulf were for July and for August, respectively 2,800 and 1,040 per liter; Gran and Braarud, 1935.

The silicoflagellate *Distephanus speculum* has also been found somewhat more common in August and September (up to 500–600 per liter) than at other times of year.

It is in July or August, if ever, that tropical species of planktonic plants may be expected to drift northward from outside into the Gulf of Main (Bigelow, 1926, p. 393). But the only cases of this sort so far recorded—apart from the fragments of Sargassum that are sometimes reported or picked up on the offshore banks, or even on German Bank (Bigelow, 1917)—have been occasional specimens of *Ceratium macroceros* detected among the boreal species of that genus off the Merrimac River in December 1920, and in small numbers at all the offshore stations in August 1936 (Fig. 9; Fig. 4, Part I of this report).

Autumnal Flora

In the coastal belt between Mt. Desert Island and Cape Cod on the one hand, and on George's Bank on the other, a mixed flora of neritic diatoms and of peridinians may persist for an indefinite period after the climax of the late summer flowering of diatoms (Fig. 11). *Sceletonema costatum*, for example, has been found in fair abundance in shoal water near Mt. Desert Island in September (1922, 1931, 1932 and 1933), also in Massachusetts Bay, where it formed nearly 100% of the moderate diatom catch late in that month of 1915. *Guinardia flaccida* was widespread in small numbers (not over ca. 150 cells per liter) over the offshore basins in September of 1933, and was flowering richly both in the northwestern part of the gulf near Seguin Island and on the eastern part of George's Bank (100,000 and 23,000 per liter), where it was, in fact, at its peak of abundance for the year. *Thalassiosira gravida* and *Coscinodiscus concinnus* accompanied by species of Chaetoceros, Rhizosolenia, Sceletonema, with a large variety of neritic and tychopelagic diatoms in small numbers, were similarly responsible for a moderately abundant flora off Penobscot Bay in mid-September of 1915. *Chaetoceros decipiens, Rh. setigera, Th. decipiens* and *Thalassiothrix longissima* played this same rôle near Mt. Desert Island in early October of that same year, and there was evidence of a brief flowering of *Thalassiothrix longissima* at various points along the western shore of the gulf at the time. Other neritic and tychopelagic diatoms also have been known to grow in relative profusion (over 1,000 cells per liter) locally in shoal water in early autumn; *Melosira sulcata*, for example, off Cape Sable and *Thalassionema nitzschioides* off Cape Cod during September 1933.

Such variety in the species which have been found flowering in moderate abundance in autumn in so few years of record added to the list of other species that occur with them in

[19] *G. tamarensis* is the only species of this genus that has been found with any frequency in the gulf.

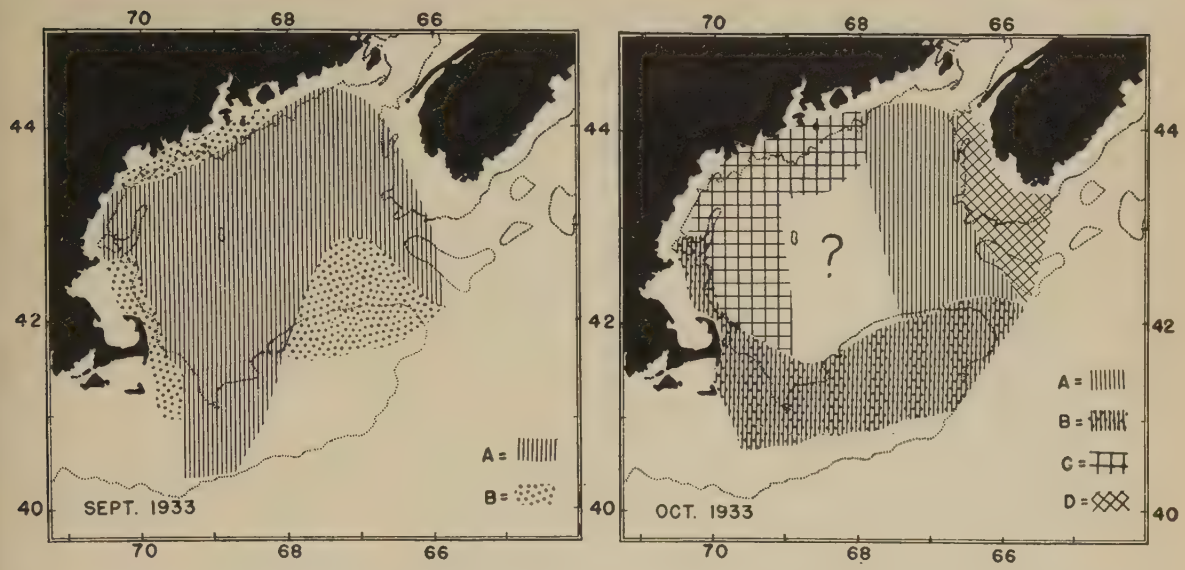

FIG. 11. Distribution of phytoplankton communities in the Gulf of Maine. Left: Early September 1933, *A*, Dinophyceae; *B*, Dinophyceae and diatoms. Right: Late October 1933, *A*, Dinophyceae; *B*, Dinophyceae and Coscinodiscus; *C*, Phytoplankton nearly or entirely absent; *D*, *melosira sulcata* and littoral diatoms.

small amounts (see following Table), emphasizes the complexity of the diatom flora of the shoaler parts of the gulf at this season, as does the fact that wide regional contrasts in this respect have been recorded within short distances.

Species to be expected in the autumn shoal waters are:

Guinardia flaccida	(temperate neritic)
Thalassionema nitzschioides	(boreal neritic)
Melosira sulcata	(tychopelagic)
Chaetoceros decipiens	(boreal neritic)
Ch. compressus	(boreal neritic)
Thalassiothrix longissima	(boreal oceanic)
Rhizosolenia setigera	(boreal neritic)
Rh. hebatata var. *semispina*	(boreal oceanic)
Rh. imbricata var. *Shrubsolei*	(temperate oceanic)
Coscinodiscus centralis	(boreal oceanic)
C. excentricus	(temperate neritic)
Thalassiosira decipiens	(boreal neritic)
Th. gravida	(boreal neritic)
Sceletonema costatum	(boreal neritic)
Pleurosigma Normani	(tychopelagic)
Exuviella spp.	
Ceratium Fusus	(temperate oceanic)
C. longipes	(boreal oceanic)
C. tripos	(temperate oceanic)
Peridinium spp.	
Prorocentrum micans	(temperate neritic).

The aestival flowering of Rhizosolenia which takes place in Vineyard Sound lasts no longer than a week, in some years not more than three or four days. Other genera are known to have a much longer period of active growth in late summer or early autumn, with Sceletonema flowering for as long as six weeks in the northern part of the gulf (Gran and Braarud, 1935); nevertheless, it seems certain that active proliferation of diatoms is usually at an end over the gulf generally by the end of September or by mid-October at latest. From that date onward—by the evidence for the several years combined—the flora appears to represent essentially the transition to the winter community (p. 197), with the genus Coscinodiscus becoming dominant in the western coastal belt and on George's Bank by the end of October (as in 1933), or at least by November (e.g., in 1916), thanks largely to the decrease in the abundance of other diatoms (Figs. 11, 12).

A sparse peridinian population dominated by Ceratium also persists throughout the autumn in the coastal waters, monopolizing any areas where diatoms—e.g., Coscinodiscus—may be absent, as it then does the offshore basin generally (data from 1933), increasing somewhat in abundance during the early part of the autumn. In September and October *C. Fusus* is usually the most abundant species of the genus over the gulf generally, but *C. lineatum* was dominant (up to 460 per liter) in the very sparse flora on the western part of George's Bank in September 1933. The highest count for *Prorocentrum micans* was found in October when there were 2,500 cells of it per liter at a station on the eastern part of George's Bank in 1933, though it was much less numerous in the deeper waters to the north at that time.

Coccoliths also persist in moderate numbers in the basin through September (up to 2,000 per column) and October (up to 1,200,000 per column, Fig. 12).

The seasonal succession of the leading genera for representative parts of the gulf is illustrated on Fig. 13.

SEASONAL FLORAL SUCCESSION IN NEARBY LOCALITIES

The following resumé of floral successions in the Bay of Fundy, tributary to the Gulf proper and in the Woods Hole region which joins it to the west and south, based on previously published information (Fritz, 1921; Fish, 1925; Davidson, 1934; Gran and Braarud, 1935; Lillick, 1937), is added to round out the foregoing account.

Bay of Fundy

In the region of Passamoquoddy Bay—the only locality within the Fundian area where the phytoplankton has been studied in winter (Fritz, 1921; Davidson, 1934), the diatoms Coscinodiscus and *Melosira sulcata* dominate during December and January, other neritic diatoms and Dinophyceae occurring in small numbers only. This flora, which strongly resembles the winter community of the western coastal waters of the open gulf (p. 200), continues essentially unchanged until April, except for some increase in February and March in the relative importance of neritic diatoms such as *Thalassionema nitzschioides* and *Sceletonema costatum*.

The spring diatom flowering is normally in progress in Passamoquoddy Bay by the latter part of April (Fritz, 1921; Davidson, 1934; Gran and Braarud, 1935), *Biddulphia aurita*, Thalassiosira and Chaetoceros developing concurrently, though they reach their peaks successively. Biddulphia, which usually appears just previous to the other species,

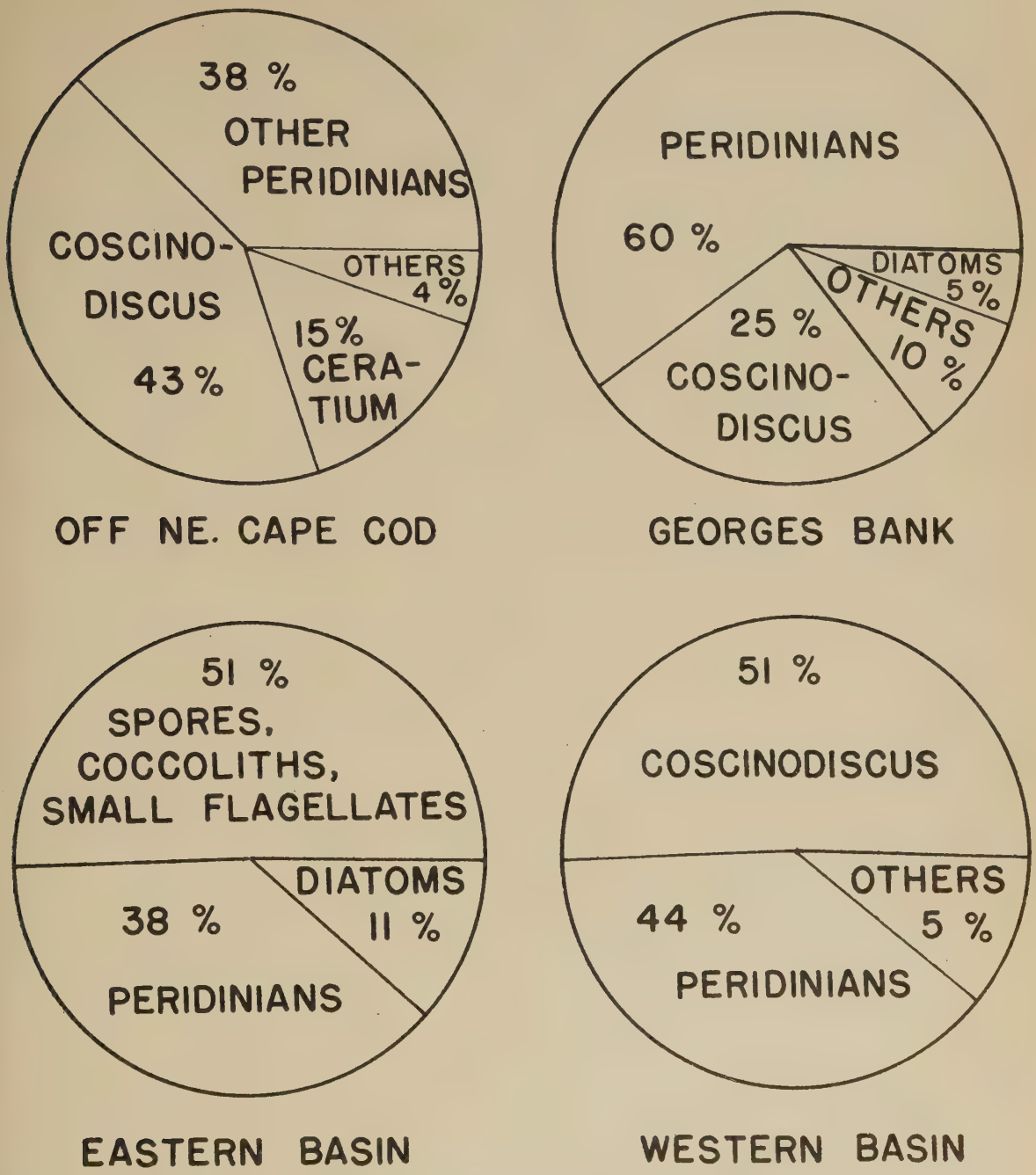

Fig. 12. Percentage composition of representative localities in the Gulf of Maine, October 1933.

reaches its maximum abundance within a few days, and then diminishes in numbers almost as abruptly, the span of its flowering seldom lasting more than two weeks, to terminate (usually) before the end of May. *Thalassiosira Nordenskioeldi* and its companion species *Porosira glacialis* multiply less rapidly, though to a higher level of abundance, to reach their maximum in April in some years, but not until June in others, with the period of

abundance lasting for about a month. The subsequent multiplication of Chaetoceros is still slower, for this genus does not reach its peak until May in an early year, but not until July or even August in a late. As a rule the water is then dominated by *Ch. debilis*, though on occasion *Ch. compressus*, *Ch.* (*diadema*) *subsecundus* or *Ch. lacinosus* may outnumber it.[20]

The spring flora—less varied in the bay than in the gulf—is dominated by the same species in both areas. The most striking contrasts between the two localities are: (1) that the vernal flowering of diatoms takes place four to eight weeks later and generally endures longer in the bay than in the gulf; (2) that *Biddulphia aurita* is a much more important item in the flora in the former than in the latter (p. 210). After the periods of active multiplication have passed—which endure about a month for Thalassiosira and six weeks to two months for Chaetoceros—these communities abruptly disappear from the surface waters of the bay, leaving behind an impoverished flora of neritic diatoms, such as *Actinoptychus undulatus*—which is more abundant in the bay than in the gulf—*Melosira sulcata*, *Thalassiosira decipiens*, Chaetoceros spp., *Leptocylindrus danicus* and *Sceletonema costatum*. This tychopelagic and neritic association, the summer minimum of Gran and Braarud (1935, p. 339), occupies much of the bay inside Grand Manan for a short period, contrasting strongly with the Ceratium flora of late spring and summer of the open Gulf of Maine (p. 221). One of its interesting features is the abundance of the silicoflagellate *Distephanus speculum* of which Gran and Braarud (1935, p. 390) had 32,500 per liter in Passamoquoddy Bay on July 30, 1932.

In August Gran and Braarud (1935) found three distinguishable communities in the bay: (1) one along the Nova Scotian coast dominated by the neritic diatom *Ch. constrictus*, (2) another along the New Brunswick coast characterized by *Sceletonema costatum*, accompanied in less quantities by *Asterionella japonica*, *Ditylium Brightwelli* and *Coscinodiscus excentricus* and (3) their "Triquetum society" (Gran and Braarud, 1935, p. 344) of small neritic peridinians such as *Peridinium faeroense*, *P. triquetum*, *P. trochoideum* and *Goniaulax tamarensis*, which was generally distributed over the bay and present but less well developed in the northern part of the Gulf of Maine. The first of these communities Gran and Braarud (1935) class as characteristic of the drift into the bay and the second of the drift out of it; the third spreads from centers near the outlet of Digby Gut and off the mouth of the St. John's River. The oceanic species *Pontosphaera Huxleyi*, *Ceratium tripos*, *C. Fusus* and *Rhizosolenia alata*, which are so prominent in the Gulf of Maine in late summer, were also numerous in the central portion of the bay at this season in the one year of record. The presence of *Asterionella japonica* as an important member of the community in the drift out of the bay suggests a source for the flowering of that species which was encountered in the open gulf in the coastal belt between the Grand Manan Channel and Seguin Island in the summer of 1912 (p. 223).

Gran and Braarud (1935) found the Constrictus and Triquetum societies reduced almost to the vanishing point in the Bay of Fundy proper by the end of September, with the *Sceletonema* association alone persisting that late in the season in fair quantity, as it does throughout the early autumn in the northern coastal waters of the open gulf likewise. A varied diatom community in which *Chaetoceros socialis*, *Thalassiothrix longissima*, *Rhizosolenia imbricata* var. *Shrubsolei* and *Ditylium Brightwelli* are prominent persists, however,

[20] For graphs showing the mutual fluctuations of Biddulphia, Thalassiosira and Chaetoceros in Passamoquoddy Bay in different years see Davidson (1934).

in the Passamoquoddy region until the end of October, when it rapidly diminishes in abundance as Coscinodiscus becomes dominant, so to continue into the winter accompanied by small quantities of the various neritic diatom species which persist almost continuously throughout the year. With the disappearance of the late summer communities from the bay, and the rise of Coscinodiscus, the flora there becomes essentially similar to that of the coastal waters of the gulf (Fig. 13).

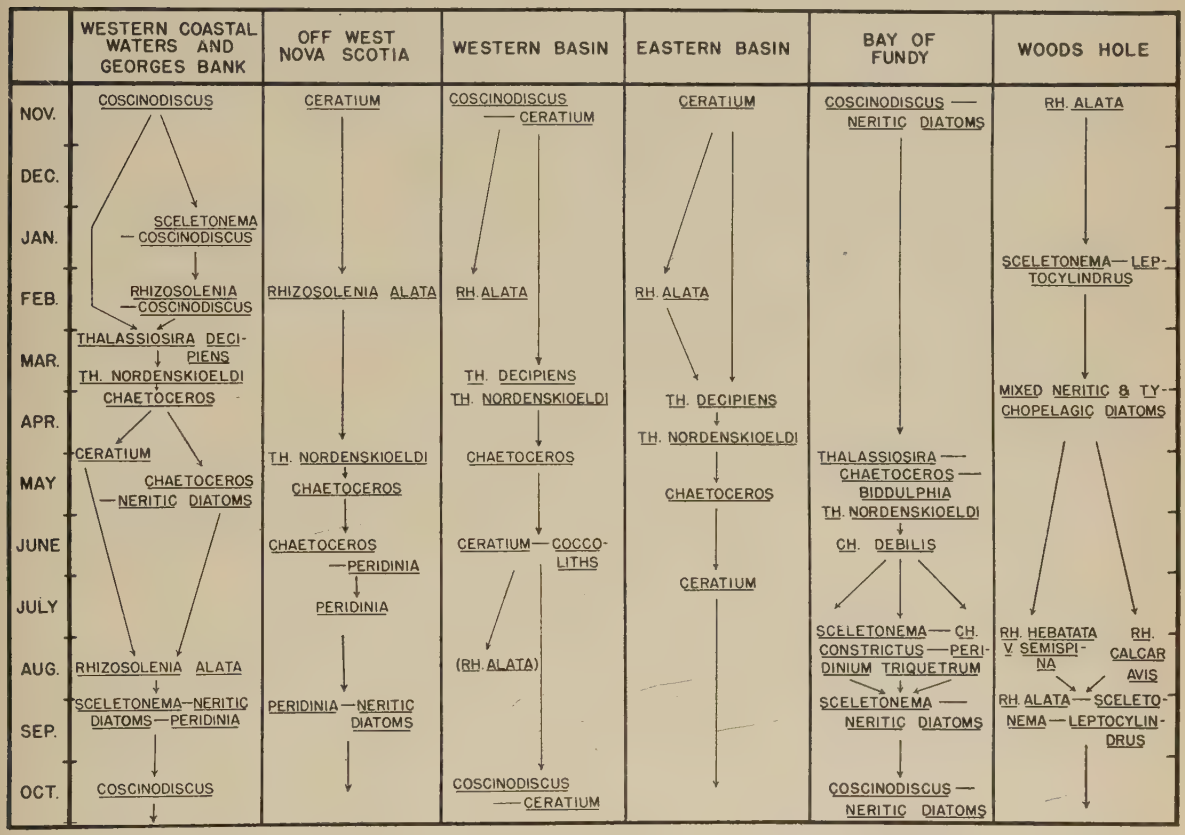

Fig. 13. Seasonal succession of dominants in representative parts of the Gulf of Maine (derived from all sources).

Woods Hole Region

Although the Woods Hole region lies so close to the Gulf of Maine, the phytoplanktonic cycle is very different there, for the main flowering of diatoms has been found to take place in the winter instead of in spring in two of the three years of record, both in Vineyard Sound and in Buzzards Bay (Fish, 1925, Lillick, 1937), commencing in mid-November, reaching its maximum in December and continuing until March when the flora suddenly diminishes in abundance (Fig. 13). Dominance in this winter maximum is shared by a large number of important species, *Rhizosolenia alata* usually leading in abundance early in the season, to be replaced later by *Leptocylindricus danicus* and by *Sceletonema costatum*. Other species that may be codominant are *Ditylium Brightwelli*, *Thalassionema nitzschioides*, *Rhizosolenia setigera*, *Rh. imbricata* var. *Shrubsolei* and *Chaetoceros socialis* (all of them

neritic) and the oceanic forms *Nitzschia seriata* and *Ch. decipiens*. In one year (i.e., 1935–1936) it appears that no definite maximum developed either in winter or in spring (Lillick, 1937).

A sparse flora consisting of neritic or tychopelagic species prevails in the Woods Hole region throughout the later spring and early summer, including *Guinardia flaccida, L. danicus, T. nitzschioides, Prorocentrum micans, P. scutellum, S. costatum, Corethron hystix, N. seriata,* species of Chaetoceros and others, but with wide variation. A second brief flowering dominated by Rhizosolenia occurs in mid- or late summer. In the four summers 1935–1938, during which the writer has observed this maximum, the dominant species was either *Rh. semispina* or *Rh. calcar-avis,* both occurring in great abundance; but *Rh. imbricata,* var. *Shrubsolei* and *Rh. setigera* were also present in numbers sufficient for either of these to dominate, if hydrographic conditions were such as to prevent a flowering of *Rh. semispina* (Fish, 1925). Small amounts of *G. flaccida, S. costatum* and peridinians likewise contribute to this flora. It has been suggested that this flowering represents a series of local swarms; actually, however, the same association of species is generally distributed over the Woods Hole area at the time. In the years of record this flowering was at its peak late in July or early in August and lasted for little more than a week. Diatoms then decreased so abruptly in abundance that only a very scanty population was left, consisting of *Rh. alata, S. costatum* and *L. danicus* accompanied by a variety of other species in minimal numbers, a situation which continues until the winter maximum again develops.

The Woods Hole flora contrasts further with that of the Gulf of Maine in the occurrence of a much larger number of small pigmented flagellates which form a significant portion of the phytoplankton there, especially during the warm months of the year (Lackey, 1936).

The Woods Hole area and the waters thence to Long Island Sound agree in seasonal schedule with the Mediterranean and with the Adriatic Seas more closely than with the Gulf of Maine, as Fish (1925) has pointed out. In fact it is only during the late summer flowering of Rhizosolenia that the Woods Hole flora resembles that of the Gulf, and even then different species dominate in the two areas.

COMPARISON WITH OTHER BOREAL REGIONS

It has already been noted by Bigelow (1926), by Føyn (1929) and by others, that the planktonic cycle of the Gulf of Maine parallels that of the North Sea and of the waters of southern Norway, both in time-sequence and in dominant species. The northern Norway Sea (Lofoten) the Irish Sea, the Clyde Sea area, the English Channel and the continental shelf off Sydney, Australia are also similar as to cycle, though not so as to species (Herdman, 1918; Herdman, Scott and Dakin, 1910; Marshall and Orr, 1926, 1929; Harvey, Cooper, Lebour, and Russell, 1935; Dakin, 1934; Dakin and Colefax, 1935). The phytoplankton cycle of the Gulf of Maine is even similar to that of certain areas of the South Atlantic (Hart, 1935), with the same or related genera dominant at comparable stages in many cases. Especially interesting in connection with the gulf is the survey Braarud and Bursa (1939) conducted in the Oslo Fjord during the same year (1933–1934) in which our general surveys of the gulf were made, for the cycle in the outer part of the fjord is typical of Norwegian coastal waters in general. In June they report an abundant diatom flora dominated by *Sceletonema costatum,* but with species of Ceratium also conspicuous. During the summer

Rhizosolenia alata, Ceratium and species of Peridinium were abundant, but by October these had been replaced by a community relatively poor in diatoms and ceratia. In December the flora consisted in the main of a weak development of Sceletonema and of the coccolithophorid *Calsiosolenia Grani*. A Thalassiosira-Porosira-Sceletonema flowering makes up the spring maximum in this region early in March, but this stage was missed by the collections. A Chaetoceros plankton was found in April, and Sceletonema in May, accompanied by *Pontosphaera Huxleyi*. The similarity between this cycle and that of the coastal waters of the Gulf of Maine (Fig. 13) is apparent. The outstanding differences are the greater prominence of Sceletonema in Norwegian waters—in European waters in general—the insignificance of Coscinodiscus in the winter flora there and a difference in the flowering dates.

The seasonal cycle of the Bay of Fundy, especially of Passamoquoddy Bay (Davidson, 1934), parallels that along the northwest coast of America from Friday Harbor, Washington, to the Aleutian Islands and Scotch Cap, Alaska (Cupp, 1937), except that the various stages follow about four to eight weeks later in the latter area. Although the specific composition of the flora of the two regions is not always the same, especially during the early spring, the same dominant genera are common to both; the chief divergent feature noted by Cupp (1937) is the greater abundance in late summer and autumn of *Asterionella japonica* in Alaskan waters than in the Bay of Fundy, a difference which is minimized in the light of recent work in the bay (Gran and Braarud, 1935).

The outstanding fact to be gleaned from these comparisons is that boreal waters, widely separated though they may be as to latitude and longitude, or by intervening land masses which prevent any direct connection by ocean currents, may bear strong resemblance one to another, both as to the cyclic production of cells, and as to the generic and even specific composition of the flora.

SUMMARY

The flora of the Gulf of Maine proper is not only scanty in early winter but also the least varied then, dominated as a rule either by Coscinodiscus, by Ceratium or by small species of other peridinian genera, the relative importance of which varies considerably from year to year, as outlined above (p. 197). Coscinodiscus reaches its maximum abundance as a whole in midwinter, with maximum frequency up to 1,600 per liter. *Rhizosolenia alata* has also been found flowering locally in moderate abundance (up to 1,300 per liter) at that season on both sides of the gulf, and increases have been recorded in late December or January for *Thalassionema nitzschioides*, for *Sceletonema costatum* and for others of the species listed on p. 203. Coincidently, however, the Dinophyceae decrease. The chief variation from year to year at this season is in the relative proportions of Coscinodiscus as compared to peridinians, and in the local development of associations of unusual composition as described on p. 205.

The outstanding alteration from winter to spring is the vernal outburst of diatoms, accompanied by a still further decrease in the number of peridinians, actual as well as relative. This outburst results chiefly from the rapid multiplication of Thalassiosira, a genus very scarce or absent in early winter, but appearing in significant numbers in late January or in February. In the open gulf *Th. Nordenskioeldi* is usually the dominant species; toward the north, however, *Th. decipiens* may equal or outnumber it, as seems to be

usual in the Bay of Fundy, and in some years *Th. gravida* also is co-dominant. *Porosira glacialis* may likewise be codominant in the bay, though not so recorded in the gulf proper. Other species characteristic of the Thalassiosira flora of spring are listed on p. 209.

The vernal flowering of Thalassiosira develops earliest in the western coastal belt, at a date varying between late February and early April in different years; soon afterward (March–mid-April) in the coastal and bank waters west and south of Nova Scotia. It is possible that early flowerings of Thalassiosira also develop on the western part of George's Bank, but the evidence is not clear in this respect. The areas occupied by the flowering of Thalassiosira extend northward along shore in both sides of the gulf to join across the mouth of the Bay of Fundy; as well as southward and offshore into the eastern side of the open basin. They also involve the western basin, though it is not known whether Thalassiosira ever dominates as strongly there (p. 208), or on the eastern part of George's Bank, as it does in the coastal waters of the gulf generally. Active multiplication of Thalassiosira is briefest —2–4 weeks—in the eastern and southeastern parts of the gulf generally, and on George's Bank, longest in the northern coastal belt (8 to 12 or more weeks) and in Passamoquoddy Bay, tributary to the Bay of Fundy. The western coastal belt is intermediate in this respect, the flowering enduring there for 4–7 weeks (average about 5 weeks).

Coincident with the vernal flowering of Thalassiosira, the eastern side of the gulf is invaded by a weak population of the cold-water peridinian *Ceratium arctica* which, however, disappears after April. After Thalassiosira has reached its peak it declines so abruptly in abundance over the open gulf that within a few days it falls to an insignificant rank in the flora. The rise and fall of *Th. Nordenskioeldi* is closely correlated with temperature, its optimum being below 5° C.

The eclipse of Thalassiosira is yearly accompanied throughout the area by an active flowering of the genus Chaetoceros, except perhaps in the eastern basin for which the evidence is conflicting. This flowering reaches its climax at about the time Thalassiosira approaches its minimum, i.e., in some time in April over the deeper parts of the gulf generally, but not until the end of May or even later in the northern coastal belt, where Thalassiosira persists longest. In any given part of the open gulf the alternation in dominance between the two genera usually takes place within 10 days, with the regional expansion of Chaetoceros correspondingly paralleling that characteristic of Thalassiosira earlier in the season. At their respective peaks of abundance Chaetoceros ranks second to Thalassiosira in the gulf (see Table, p. 213). During its vernal peak 15 species of Chaetoceros have been identified (Table I), most of them, however, being in small numbers. The most frequently dominant is *Ch. debilis*, as may be *Ch. constrictus* also in some years. Other species have also been found dominant locally as described on p. 214. Present indications are that the normal duration of active vernal flowering for Chaetoceros is 4–6 weeks over the gulf generally, i.e., until late April or some time in May. But the fact that, although its period of rapid multiplication endured for 3 weeks only near Cape Ann in 1938, this continued throughout the early summer (i.e., for more than 8 weeks) in the western coastal belt in 1914 and again in 1934, shows that considerable variation is to be expected in this respect from year to year, as is also the case in the Bay of Fundy.

In general, Chaetoceros declines as abruptly in abundance as does Thalassiosira in the open gulf, once its peak of abundance is passed—for illustration of this see p. 213; in some years, however, it may persist in moderate numbers throughout the entire summer at scattered localities in the western and northern coastal belts. In 1920 the eclipse of Chae-

toceros was succeeded in Massachusetts Bay by a brief but intense flowering of Phaeocystis, but this is the only such record for the gulf; hence it is doubtful whether it is a regular event in the seasonal cycle, or whether the case in point was a sporadic occurrence.

Diatoms of one or another of the species listed on p. 221 continue to dominate the flora throughout the summer on George's Bank, locally, however, and sporadically, and are sometimes outnumbered there by Pontosphaera. They may also dominate an impoverished flora all summer in the northern coastal belt in some years. In other years, however, the eclipse of Chaetoceros leaves this latter belt barren of diatoms and dominated by a sparse dinophycean flora, as it does the coastal belt farther south and the bowl of the gulf as a whole, at a date varying locally and with the years between the end of May and the end of June or beginning of July. In the eastern coastal belt the situation is complex, requiring more extensive data for its clarification. The peridinian flora of summer is dominated by species of Ceratium among which *C. tripos*, *C. longipes*, *C. bucephalum* and *C. Fusus* are the most important, accompanied by the other peridinians, diatoms and coccolithophorids listed on p. 218. Earlier accounts of the mutual fluctuations in abundance of *C. longipes* and *C. tripos* (Bigelow, 1926) are confirmed by the data for more recent years.

Chief alteration of the flora during the late summer is such as results from the local development of second flowerings of diatoms, Rhizosolenia being chiefly responsible for these in the shoaler waters including George's Bank. For details as to abundance at this season of individual species of this genus see p. 222. Chaetoceros may also have a distinct second flowering close inshore in the northern coastal belt, and *Guinardia flaccida* is an important component of the late summer flowering, especially on George's Bank. *Sceletonema costatum* also has its maximum in late summer (up to 700,000 cells per liter) when it may dominate locally inshore (as near Mt. Desert Island, off Nova Scotia and in Nantucket Sound) in August, and in Massachusetts Bay in September. *Thalassiothrix longissima* similarly dominated a rich flora on the western part of George's Bank late in July 1916, and *Asterionella japonica*, a species widespread in summer in the Bay of Fundy, but usually scarce or wanting in the open gulf, flowered in great abundance in the northern coastal belt in August of 1912. Peridinians are overshadowed in the shoaler parts of the gulf during the late summer flowerings of diatoms, but the same species persist there as in early summer, and in undiminished quantity, besides others as listed on p. 221. Peridinians as a group dominate in the bowl of the gulf generally throughout the summer except on the western side, to which the Rhizosolenia flowering may extend from the coastal belt, as described on p. 226. It is at this season, also, that coccoliths are at their maximum—notably *Pontosphaera Huxleyi*, a population of nearly 300,000 of which per liter was recorded on George's Bank and in the neighboring basin in July 1933 (Braarud, 1934). The only record of unicellular plants of tropical origin in the gulf is of occasional *Ceratium macroceros*.

Sceletonema has been found flowering during the first half of September in the northern gulf and until late in that month in Massachusetts Bay. Guinardia also was in great abundance near Seguin Island and on the eastern part of George's Bank in early September 1933, when other diatoms also in wide variety were recorded at one station or another. In fact it is at this season that the diatom flora may be the most varied (for list of species see p. 227) and the regional contrasts widest in its qualitative composition. Active proliferation of diatoms is generally ended, however, in most parts of the gulf by the end of September or by early October, even in localities where it persists the latest. From that

time onward the flora gradually assumes the early winter state, the quantitative impoverishment of diatoms as a group leading once more to a sparse flora dominated by Coscinodiscus, by peridinians, or by the two in combination.

The seasonal cycle is essentially the same in the Bay of Fundy as in the open gulf except that Biddulphia is a more important factor in the vernal flowering, that the vernal peaks of abundance for Thalassiosira and Chaetoceros develop later in the bay and endure longer there, and that tychopelagic and neritic diatoms of the species named on p. 230 are relatively more important there in summer, and Peridinians relatively less so.

In the Woods Hole region, however, the maximum flowering takes place three months earlier in the season than in the gulf (i.e., mid-November to early March), and is chiefly of species that are of little importance in the winter-spring flora of the latter, whereas Thalassiosira—the leading genus in the gulf—is negligible westward from Cape Cod.

The records for 1933–1934 corroborate earlier observations that the cycle of planktonic plant production in the Gulf of Maine closely parallels that of boreal waters generally on the opposite side of the North Atlantic in time-sequence, though different associations of species may dominate the peaks of abundance in different localities, under different environmental conditions.

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PRELIMINARY RESULTS OF MEASUREMENTS OF TEMPERATURE- AND SALINITY-VARIATIONS IN THE GULF STREAM: MARCH 1940

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(Contribution No. 263 of the Woods Hole Oceanographic Institution)

Repeated measurements of temperature and salinity over extended periods from anchored vessels have shown that significant short-period variations of oceanographic properties occur at fixed points in the ocean-space. The phenomenon, observed to great depths in the ocean-basins, arises because of internal vertical and lateral motions of the water-layers; in regions of not too strongly sloping isohaline and isothermal surfaces (as the western Sargasso Sea), vertical displacements dominate, whereas elsewhere (as the Gulf Stream) both lateral and horizontal displacements may be effective. Large diurnal temperature-variations have been recorded in the western Atlantic, where for considerable distances in all directions isothermal surfaces are only slightly sloping, and, as a result of scattered investigations, it is to be inferred that the phenomenon is of general occurrence and that somewhat corresponding results could be observed in all oceans. Thus, during 14 days of continuous observations at Atlantis station 3091 (about 110 miles northwest of Bermuda), 24 hourly temperature-ranges up to 2°50 were observed at depths of 800 meters, up to 1°45 at 1,000 meters, and up to 0°31 at 1,300 meters.

In oceanic regions of strongly sloping isothermal and isohaline surfaces where lateral, as well as vertical displacements, may be of equal significance, even greater diurnal temperature-variations occur at fixed depths. Thus, at Atlantis anchor station 3777 (28° 55' north, 79° 36' west), located in the axis of the Gulf Stream off Cape Canaveral, a maximum diurnal temperature-range of 3°38 at 250 meters and a salinity range of 0.57 °/oo at 350 meters were recorded during 48 hours of continuous measurement (04^h 52^m February 12 to 04^h 16^m February 14, 1940, GCT). Diurnal inequalities in amount of disturbance are brought out by comparison of 24 hourly temperature-ranges (Table 1). During the first period (maximum temperature-range 3°38), temperature-ranges at three depths were in excess of 2°, at four depths in excess of 1°5, and at ten depths in excess of 1°0, whereas during the second (maximum range 2°15) the range at only one depth was in excess of 2°, at three depths in excess of 1°5, and at 11 depths in excess of 1°0.

Since anchor station 3777 was located in that part of the Gulf Stream where isothermal and isohaline surfaces were most tilted, and since its position, determined on the basis of a hydrographic section across the current, closely coincided with that of hydrographic station 3773 (29° 00' north, 79° 37' west), horizontal gradients in its immediate vicinity may be estimated from observations at adjacent hydrographic stations 3772 (28° 58' north, 79° 29' west) and 3774 (29° 00' north, 79° 45' west) [distance between stations 3772 and 3773 = 19.49 km and between 3773 and 3774 = 12.99 km]. Temperature-gradients both east and west of 3773, in general, increased downward from the surface; to the east (3772 - 3773), average horizontal temperature-

Table 1--Summary of temperature- and salinity-variations at fixed depths, Atlantis anchor station No. 3777 (28° 55' north, 79° 36' west)

[Minimum and maximum temperatures and salinities and total ranges for entire 48-hour observation period (04^h 52^m February 12 to 04^h 16^m February 14, 1940, GCT), first-day temperature-range for observations during first 24-hour period, second-day temperature-range for second 24-hour period; salinity-estimations made on alternate samplings]

Depth	Temperature					Salinity		
	Minimum	Maximum	Total range	24-hour range 1st day	24-hour range 2nd day	Minimum	Maximum	Total range
	°	°	°	°	°	‰	‰	‰
0	23.0	24.1	1.1	0.3	1.1	36.19	36.34	0.15
50	22.90	23.65	0.75	0.30	0.71	36.14	36.42	0.28
100	22.50	23.60	1.10	0.39	1.10	36.16	36.60	0.44
150	21.13	23.54	2.41	2.41	1.34	36.22	36.64	0.42
200	19.89	22.04	2.15	1.99	2.15	36.25	36.76	0.51
250	16.60	19.98	3.38	3.38	1.52	36.20	36.62	0.42
300	14.70	17.11	2.41	2.25	1.11	35.92	36.31	0.39
350	13.08	15.16	2.08	1.32	1.06	35.66	36.23	0.57
400	11.50	13.82	2.32	1.13	1.32	35.45	35.78	0.33
450	10.15	11.71	1.56	1.06	0.60	35.26	35.47	0.21
500	8.95	10.45	1.50	1.19	0.90	35.02	35.30	0.28
550	8.00	9.56	1.56	1.37	1.54	34.97	35.21	0.24
600	6.80	8.28	1.48	1.25	1.11	34.89	35.00	0.11
650	6.65	7.80	1.15	0.60	1.01	34.87	34.94	0.07
700	6.61	7.61	1.00	0.19	1.00	34.87	35.02	0.15
750	6.65	7.26	0.61	0.24	0.61	34.96	35.06	0.10

gradients increased from 5.131×10^{-8} degrees per cm at the surface to 207.275×10^{-8} at 550 meters, with a secondary maximum of 129.290×10^{-8} at 150-meter depth; and, to the west (2773 - 2774), average horizontal gradients changed from 76.988×10^{-8} at the surface to 359.535×10^{-8} at 350-meter depth, with a secondary maximum of 173.223×10^{-8} at 100 meters. Horizontal temperature-gradients west of station 3773 were, on the average, three times as great as those to the east.

Vertical temperature-gradients at station 3773 were, for equivalent depths, between 83.9×10^3 (at 550 meters) and 4.41×10^3 (at 100 meters) times greater than horizontal gradients to the east (3772 - 3773); eliminating these two extreme values, the ratio of vertical to horizontal gradients to the east $[(\Delta T°/\Delta Z/(\Delta T°/\Delta D)]$ lay between 2.12×10^2 and 7.65×10^2 with an average value for the water column of 7.315×10^2. On the other hand, vertical gradients at station 3773 were between 29.2×10^2 and 8.58×10^2 times greater than those to the west, and eliminating the three lowest values (at 25, 50, and 350 meters), the ratios $[(\Delta T°/\Delta Z/(\Delta T°/\Delta D)]$ lay between 1.11×10^2 and 8.58×10^2; the average for the water-column being 2.363×10^2.

Trends of horizontal salinity-gradients in the vicinity of station 3773 were similar to temperature; eastward (3772 - 3773), in general, they increased from 0.513×10^{-8} at the surface to 27.705×10^{-8} ‰ per cm at 550 meters; and westward (3773 - 3774), from 6.929×10^{-8} at the surface to 45.423×10^{-8} ‰ per cm at 350 meters. The average of all horizontal gradients to the west of station 3773 was in excess of three times the average of those to the east. Ratios of vertical to horizontal salinity-gradients $[(\Delta S/\Delta Z)/(\Delta S/\Delta D)]$ averaged 6.50×10^2 to the east and 2.49×10^2 to the west.

Thus, lateral cross-stream displacements of the water-layers of a magnitude between 100 and 1,000 times that of vertical displacements are required to produce the observed diurnal variations of temperature and salinity at station 3777. Since a concept of large-scale lateral swingings of the water-layers is not in contradiction to modern hydrodynamical theory, it seems likely that the observed variations of temperature and salinity at fixed points are a combination of both internal vertical and lateral motions on the water-layers, although their relative effects cannot be separated on the basis of existing information. However, in order to approximate the amounts of vertical and lateral displacements needed to produce the observed diurnal variations, the situation was first examined with respect to the amount of vertical displacements alone. The procedure was carried out by computing assumed vertical displacements of selected isotherms during 24-hour periods, and during the first period vertical displacements ranging from 35 meters for the 12° isotherm (386-421 meters) to 86 meters for the 7° isotherm (592-678 meters), and

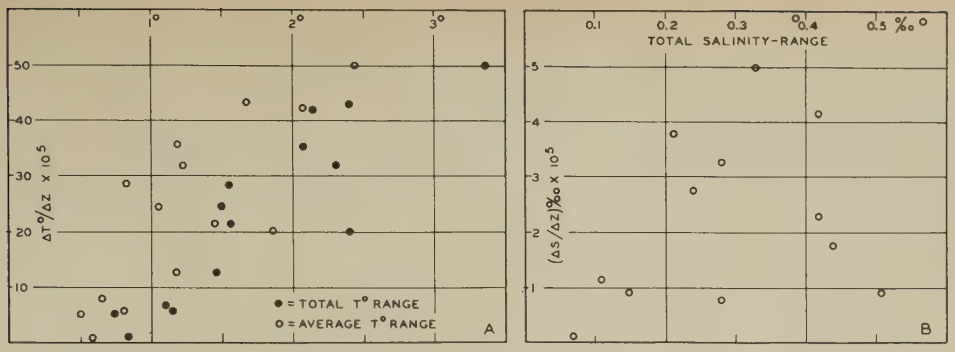


Fig. 1--A = Relationship between total (closed circles) and 24 hourly (open circles) temperature-ranges and vertical variation of temperature ($\Delta T/\Delta Z$); B = Relationship between total salinity-range and vertical variation of salinity ($\Delta S/\Delta Z$), anchor station 3777

during the second period vertical displacements between 16 meters for the 12° isotherm (422-438 meters) and 162 meters for the 7°.25 isotherm (584-746 meters) would be required. Reference to Table 1 shows that 24 hourly temperature-ranges were about double at the mean depth of the 12° isotherm where vertical temperature-stratification of the water-column was approximately six times that at the depth of the 7° isotherm. On the other hand, horizontal temperature-gradients at the mean depth of the 7° isotherm were approximately twice as great as at 12°, indicating that lateral displacements would be approximately two times as effective as vertical displacements.

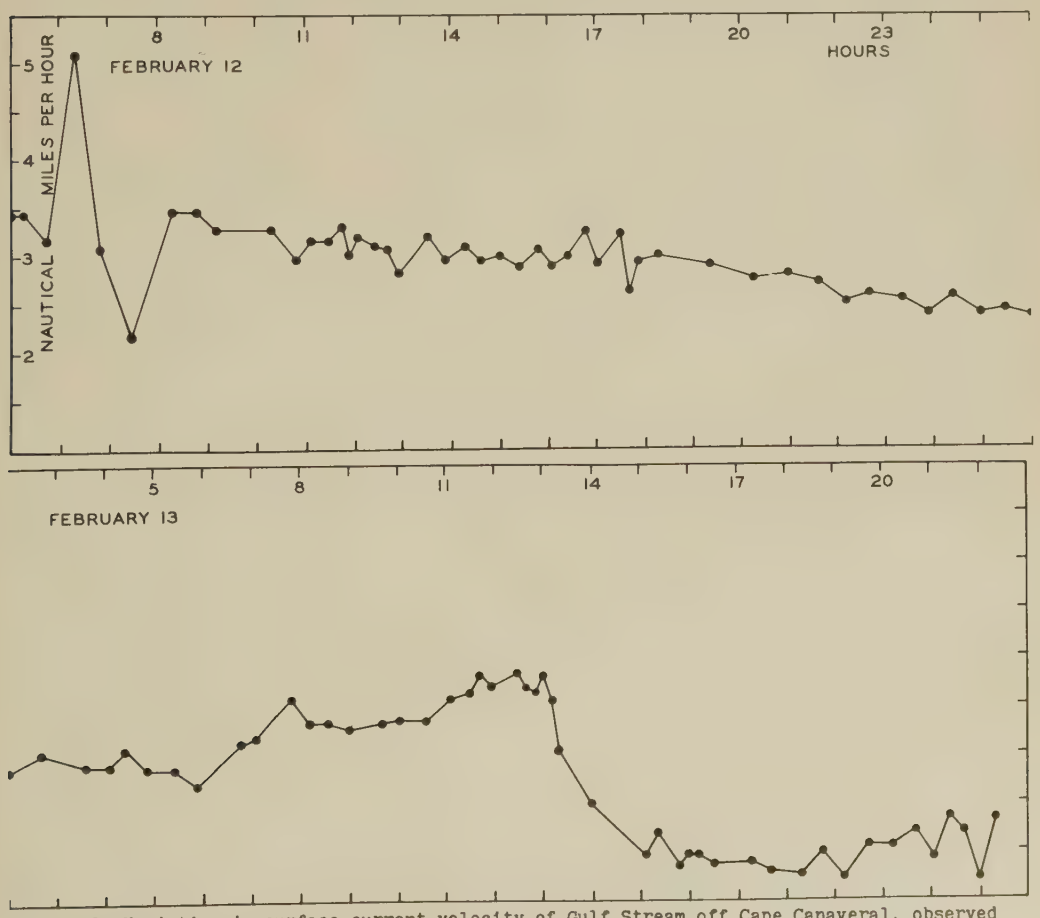


Fig. 2--Variation in surface-current velocity of Gulf Stream off Cape Canaveral, observed $10^h\ 00^m$ GCT, February 12, 1940, to $03^h\ 30^m$, February 14, 1940, anchor station 3777

General relationships between 24 hourly temperature- and salinity-ranges and the physical structure of the water-column at station 3777 are not unlike the situation as found in other regions of the western Atlantic. Total and average temperature- and salinity-ranges (Table 1), particularly the former, closely follow their own vertical gradients, being greater at depths where the vertical gradients are greatest (Fig. 1). Thus, the larger average variations of 2°.46 and 0.44 ‰ occurred at depths between 150 and 400 meters where average vertical gradients of temperature and salinity were $(\Delta T/\Delta Z) = 37.38 \times 10^{-5}$ degrees per cm and $(\Delta S/\Delta Z) = 4.01 \times 10^{-5}$ ‰ per cm, as compared with the lesser average ranges of 1°.38 and 0.18 ‰ between 450 and 700 meters where average vertical gradients of temperature and salinity were 15.82×10^{-5} and 2.00×10^{-5}. On the other hand, horizontal gradients of temperature and salinity on either side of station 3777 were lower between depths of 150 and 400 meters [$(\Delta T/\Delta D) = 119.62 \times 10^{-8}$, $(\Delta S/\Delta D) = 18.55 \times 10^{-8}$] and higher in the deeper water [$(\Delta T/\Delta D) = 158.02 \times 10^{-8}$, $(\Delta S/\Delta D) = 22.75 \times 10^{-8}$ between 450 and 550 meters]. The situation suggests that over a large part of the water-column at station 3777 time-variations of oceanographic properties at fixed depths are dominated more by vertical than by lateral displacements of the water-layers.

That significant lateral displacements may affect the uppermost layers of the Gulf Stream is suggested by time-variations of surface current-velocity of between 5.1 and 1.2 nautical miles per hour, observed during a 41-hour period at anchor station 3777 (during light southerly winds, 0-2), with a small taffrail log, read at approximate 15-minute intervals (Fig. 2). Surface velocity-gradients as computed for the Gulf Stream section clearly illustrate possible effects of lateral motions of the surface-layer on velocity-variations at fixed points. Thus, maximum surface-velocities at 168 cm per sec midway between stations 3773 and 3774 decreased easterly to 15 cm per sec between stations 3771 and 3772 (39,780 meters) and westerly to 63 cm per sec between 3774 and 3775 (18,670 meters). The average surface-velocity over the 41-hour observation period at anchor station 3777 was 134 cm per sec, nearly agreeing with the computed surface-velocity of 145 cm per sec at hydrographic station 3773.

Woods Hole Oceanographic Institution,
Woods Hole, Massachusetts

Contribution No. 265

A NEW BATHYAURINIA FROM OFF NORTHERN FLORIDA (*)

BY WILLIAM J. CLENCH

During the winter cruise (1940) of the *Atlantis* six bottom hauls, stations no. 3,778 to 3,783, were made 140-160 miles off St .Augustine, Florida. The mollusks collected were very limited but the dredge brought up two specimens of a new *Bathyaurinia* that is remarkable for its bright orange coloration.

Bathyaurinia aguayoi new species

(Plate 42, fig. 4)

Description. — Shell rather solid, rather elongate and shining. Whorls 5, and moderately convex. Color a light burnt orange with a narrow subsutural band and the area below the periphery suffused with darker orange. Aperture elliptical and somewhat lengthened. Spire acute and moderately lengthened. Suture well defined, not indented but "shingled" upon the whorl above and having, as well, a slight subsutral depression. Lip somewhat thickened with its upper margin slightly recessed at its junction with the whorl above. Margin of lip slightly sinuous in profile view. Columella slightly twisted and continued into a moderately lengthened canal which is arched forward. Sculpture of rather fine axial costae developed mainly on the early whorls, becoming obsolete on the body whorl. Spiral sculpture apparently confined to the body whorl and consisting of exceedingly fine threads visible on the upper and mid areas in a glance of light though much stronger and visible with the unaided eye toward the base. Mid whorls not spirally sculptured but possessing a very fine pustulose surface, visible with a 14 × lens. Nuclear whorls a very pale orange white, devoid of sculpture and possessing a sharply pointed calcarella nucleus. There is no operculum present, nor are there any columellar plicae.

The radula, which measured 7 mm. in length and .20 mm. in width, (fig. 1) consists of a single row of rachidian teeth. It has a somewhat narrow but strong basal plate supporting a large central denticle and two small lateral denticles. In length, this radula greatly exceeds that of *B. torrei* Pilsbry which we found to be only 2 mm. in length

(*) Contribution No. 265 of the Woods Hole Oceanographic Institution.

for a shell one-half the size of the present new form. However, growth of this organ may not be at all proportionate to the size of the shell.

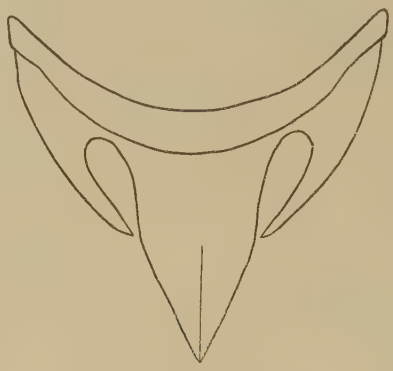


FIG. 1

Rachidian tooth of the radula of *Bathyaurinia aguayoi.*

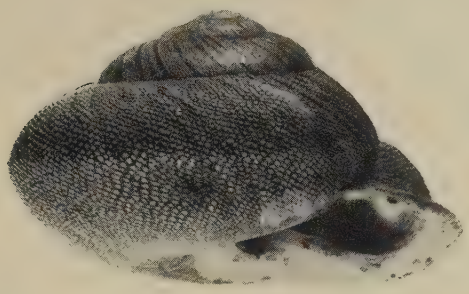
Length	*Width*	*Aperture*	
75	27.5	52 × 12.5 mm.	Holotype
77.1	32.5	57 × 13.5 „	Paratype

Holotype. — Mus. Comp. Zoöl. no. 111,858, *Atlantis* station 3,783 (N. Lat. 30° 03′; W. Long. 78° 37′) about 164 miles east of St. Augustine, Florida, in 425 to 430 fathoms. A single dead paratype from station no. 3,782 (N. Lat. 30° 10′; W. Long. 78° 44′), about 158 miles east of St. Augustine, Florida in 435 to 440 fathoms.

Remarks. — Two specimens only of this very beautiful species were collected, the holotype obtained alive, the paratype, dead but in good condition. The holotype is slightly immature, with a thin lip, the paratype, however, has developed a moderately thickened lip.

In relationship, it is apparently nearest to *B. piratica* C. and Ag. recently described from off the north coast of Cuba. From this species it differs by having smaller and a much narrower shell and lacking the pronounced shoulder of the latter form. From *B. torrei* Pils., the only other species in this genus, it differs by being smaller, lacking the shoulder, the irregular color spots and especially lacking the rather strong axial costae so characteristic of the sculpture of this latter species.

It is with pleasure that I have the opportunity to name this species after my friend and co-worker, Doctor C. G. Aguayo, Professor of Zoology, at the Universidad de la Habana.



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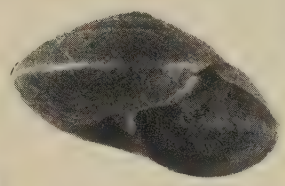

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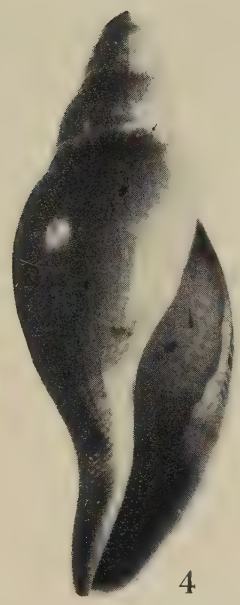

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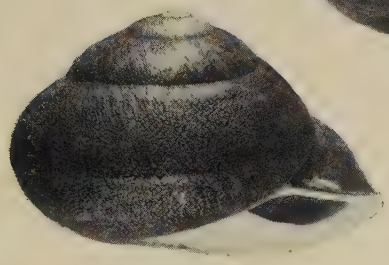

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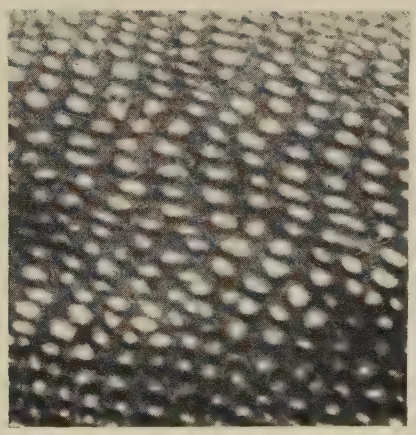

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FIG. 1. – *Polydontes lima* Fér. 2 ×.
„ 2. – *Polydontes maricao* Clench. Holotype. 2 ×.
„ 3. – *Plagioptycha euclasta beattyi* Clench. Holotype. 3 ×.
„ 4. – *Bathyaurinia aguayoi* Clench. Holotype. Nat. size.
„ 5. – *Polydontes maricao* Clench. Holotype. 8 ×.
„ 6. – *Polydontes lima* Fér. 8 ×. (Manati, Puerto Rico).

Contribution No. 266

LIMNOLOGICAL SOCIETY OF AMERICA

Special Publication No. 5

The Plankton Sampler—an Instrument for Quantitative Plankton Investigations

by

G. L. Clarke and D. F. Bumpus
Harvard University and Woods
Hole Oceanographic Institution
Contribution 266

Ann Arbor, Michigan, U. S. A.
October, 1940

THE PLANKTON SAMPLER—AN INSTRUMENT FOR QUANTITATIVE PLANKTON INVESTIGATIONS

G. L. Clarke and D. F. Bumpus

The plankton sampler is essentially a closing plankton net equipped with a flow meter. It was developed to meet a long-felt need for an easily handled device by means of which plankton could be secured from any desired depth in the sea or in inland waters and an estimate obtained of the volume of water from which the organisms had been removed. The instrument was originally designed to catch effectively the copepod element of the marine zooplankton, but three years' experience has shown that it is suitable for taking larger forms such as sagittae, euphausiids and amphipods, as well as for the smaller types of marine animals (including eggs and larvae) and for the fresh water zooplankton. The sampler has also been found useful for the collection of those types of phytoplankton (both fresh-water and marine) which are retained adequately by silk netting.

As originally designed the sampler was intended to be towed from a heavily weighted wire cable handled by means of a power winch such as is available on the larger research boats. The instrument can be operated, however, on a light cable or rope from a boat of any size and samplers have been used successfully from row boats (either rowed or propelled by an outboard motor) and from small power boats as well as from the research vessel "Atlantis". Although the sampler weighs only 10 lbs., it is ruggedly constructed and may be used in rough weather without injury.[1]

Plan of operation[2]

The plankton sampler is intended to be towed horizontally (or obliquely) from a cable kept as nearly vertical as possible by means of a weight attached to the lower end. The instrument consists essentially of a brass tube, five inches in diameter and about six inches long, to the rear end of which any one of a set of interchangeable nets (about 2 ft. long) of any desired mesh may be secured by means of a ring with a bayonet lock (Fig. 1). The tube (A in figure) is mounted on the frame (F) and this is attached directly to the supporting cable (G). The attachment of the tube to the frame is by means of pivots (H) which allow the tube to turn in the vertical plane with the result that, when towed, it assumes a horizontal position regardless of the angle which the support-

1 Samplers have been put in use by the following in addition to the Woods Hole Oceanographic Institution:
Dr. C. Juday, University of Wisconsin for the Trout Lake Laboratory.
Dr. E. B. Powers, University of Tennessee, Knoxville, Tennessee.
Dr. T. H. Langlois, Stone Laboratory, Put-in-Bay, Ohio.
Dr. J. B. Lackey, United State Public Health Service, Cincinnati, Ohio.
Dr. G. W. Prescott, Albion College, for work in Panama Canal.
Dr. C J. Fish, Narragansett Marine Laboratory, Kingston, Rhode Island.
Dr. W. F. Hampton, Fisheries Research Institute, St. John's Newfoundland.
Dr. W. L. Tressler, Chesapeake Biological Laboratory, College Park, Maryland.
Mr. W. Vogt, for work under the Peruvian National Guano Administration.

2 We are indebted to Prof. C. O'D. Iselin and to Prof. E. E. Watson for valuable suggestions in regard to the design of the plankton sampler.

ing cable makes with the vertical. Two planes (I) mounted at an angle on the tube toward the rear assist in keeping the tube horizontal. The attachment of the frame to the cable is accomplished by means of a

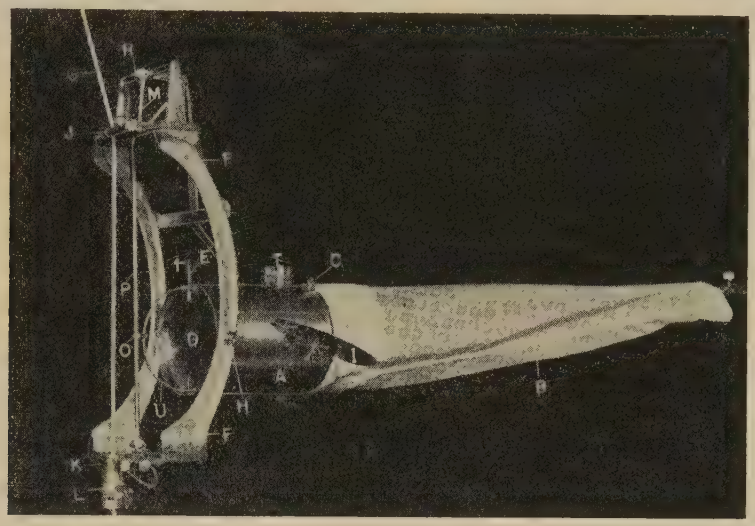

Figure 1.
Side view of plankton sampler attached to supporting cable. The shutter is in the initial closed position. For Key see Fig. 2.

loosely fitting spring pin (J) at the top and a gate lock (K) at the bottom. The latter closes around the neck of the supporting clamp (L) which is secured rigidly to the cable. In this way the frame is allowed to swivel freely around the cable and thus the opening of the tube is always directed forward when the boat is moving ahead.

At the front end of the tube a shutter is provided which consists of a disc (D) mounted on vertical pivots (E), thus taking the form of a damper in a stove-pipe. Preparatory to making a plankton haul, the shutter is turned against the spring (1) to the initial closed position (Fig. 1) where it is held by the semicircular bar (U) which engages one of two finger lugs (0_2) mounted at right angles to each other on the rod (P). In a cap at the top of this rod two arms (N_1 and N_2) are mounted at right angles to each other, and one of these (N_2) engages the rod (M) extending downward from the trigger (R).

When the sampler has been lowered to any desired depth, a messenger (Q_1, Fig. 2), weighing about a pound and consisting of a cylinder provided with a slot which is closed by two retractable pins, is then slipped over the supporting cable and allowed to slide down. When this messenger strikes the sampler, it trips the trigger (R) and allows the shutter to rotate thru 90° thus bringing it into the open position where it is stopped by the longer of the finger lugs (O_1). Rod (P) is prevented from turning too far by the escapement rod (V). The water now flows into the tube and out through the pores of the netting leaving the plankton behind

to accumulate in the apex of the conical net (Fig. 1 and 2). At the end of the towing period of any desired duration a second messenger (Q_2) is allowed to slide down the cable. This messenger again depresses trigger (R), which has returned to its original position, and allows the

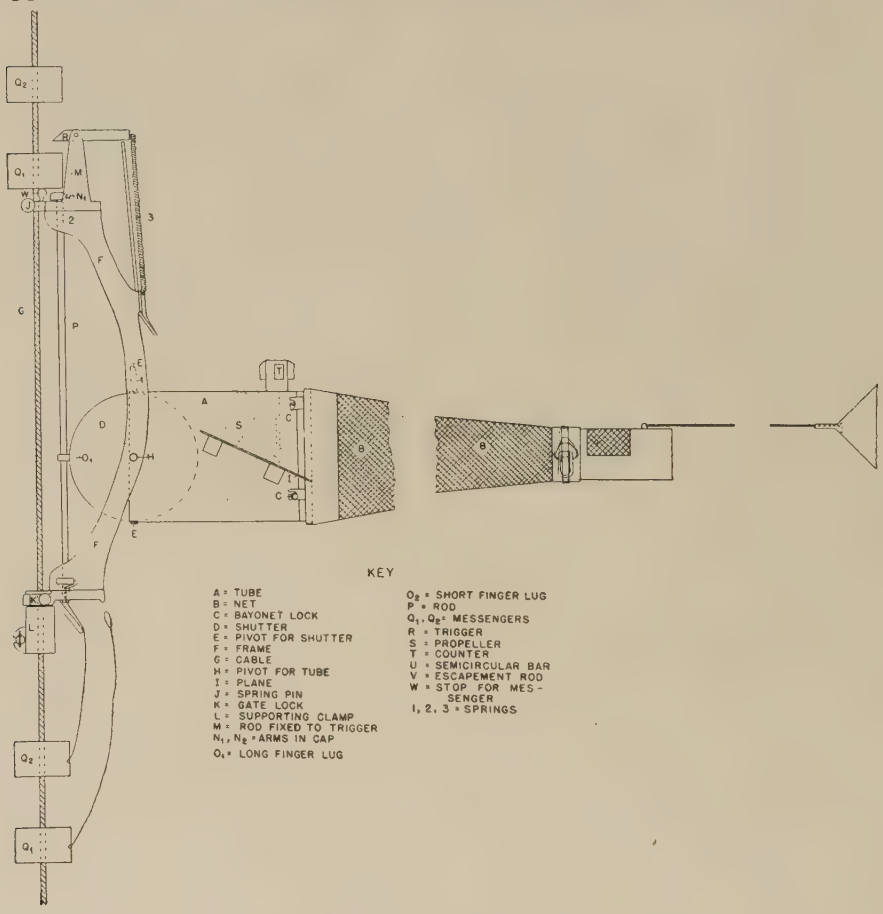

Figure 2.

Idealized side view of sampler with shutter in open position, the first messenger having tripped the trigger for the first time. The first messenger of the second set below the instrument has been cast off. A brass cup with draining window is shown clamped to tail of net with a drag attached.

shutter to rotate thru a second 90° thus closing the mouth of the tube. The sampler may then be hauled to the surface without contamination from the plankton in the overlying water strata.

Within the rear half of the tube a large propeller (S) is mounted (Fig. 2 and 4). This is geared to a counter (T) of the cyclometer type which indicates the number of revolutions and hence the volume of water which has passed through the tube and net. The meter starts

when the shutter opens and stops when it closes. It is therefore unnecessary to know the exact time when the messengers strike.

The tail of the net may be provided with a threaded brass ring (two inches in diameter) into which a small glass preserve jar may be screwed. If it is found desirable to turn the tail of the net inside out for thorough washing, it is preferable to finish off the end of the net with an elastic cuff. The cuff may be tied over the mouth of a bottle, or secured by means of a throw clamp to a small brass cup provided with a draining window covered by fine wire netting (Fig. 2).

Simultaneous hauls

The samplers have been so designed that two or more of them may be attached to the same cable at any desired intervals and operated simultaneously. At the base of rod (P) in each sampler two hooks of unequal length are provided on which an additional set of messengers may be hung by means of wires. The rotation of rod (P) following the arrival of the messenger coming from above each sampler allows first one and then the other of the second set of messengers to be released below the instrument and to travel on down the cable to the sampler below. By the simultaneous use of several samplers at different depths accurate information may be obtained as to the vertical distribution of the plankton within any given area.

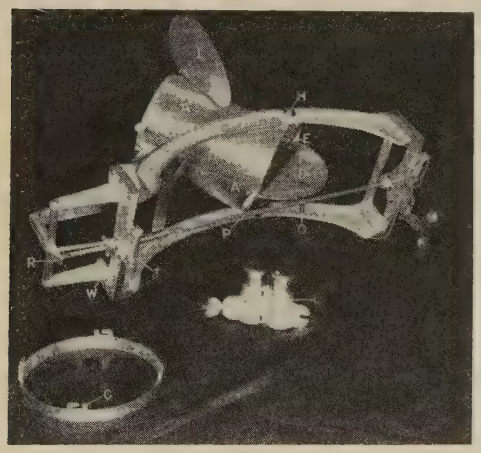

Figure 3.
Sampler lying on table with net removed, gate lock (K) open and shutter (D) in open position, clamp (L) in open position and ring for attachment of net also shown. For Key see Fig. 2.

Open Samplers

If the closing feature of the sampler is not required, the tube with the volume meter but without shutter may be mounted directly on a light rectangular frame (Fig. 5) thus greatly simplifying the whole device. The frame may conveniently be secured at the end of a light rope and a weight of any desired size placed beneath.

Calibration

The calibration of the meter in the sampler in terms of liters filtered per revolution recorded by the counter may be accomplished in suitably equipped laboratories by passing known volumes of water through the instrument at various speeds. The five instruments in use at the Woods Hole Oceanographic Institution have been calibrated in this way and show ratings of 3.8, 4.0, 4.0, 4.3, and 4.5 liters per revolution respectively.

In each case this rating was found to vary by less than 5% for speeds of flow corresponding to boat velocities ranging from ½ knot to 4 knots. The importance of this constancy in calibration rating is that it is unnecessary to know accurately the boat's speed as long as it is between these values. Furthermore, any clogging of the net, which has heretofore seriously interfered with quantitative work, is not a source of error with the plankton sampler, since the meter records only that volume of water which has actually passed through the net.

Operating Instructions

a) Setting the shutter

The shutter of the sampler is best set before the instrument is attached to the cable. Start with the shutter in the final closed position, i. e. with the semicircular bar (U) inside tube (A). Now rotate the shutter through 90° against its spring (counterclockwise looking down on sampler) and at the same time rotate rod (P) clockwise against its spring (2) until the edge of the shutter engages with the longer of the two finger lugs (O_1). At this point the first of the short horizontal arms (N_1) mounted in the cap at the top of rod (P) should engage with the rod (M) extending downward from the trigger (R). If the position of this arm is not exactly correct it may be adjusted by means of the set screw in the cap. Now rotate the shutter through a second 90° (also counterclockwise) and at the same time rotate rod (P), clockwise as before, until the semicircular rod (U) attached to the shutter engages the shorter of the finger lugs (O_2), and the rod (M) from the trigger engages the second of the horizontal arms (N_2). The tension of the springs may be increased by removing the stops and giving the shafts extra turns in the direction opposite to their operation. The shutter has now been brought into the cocked closed position and the sampler is ready for attachment to the cable.

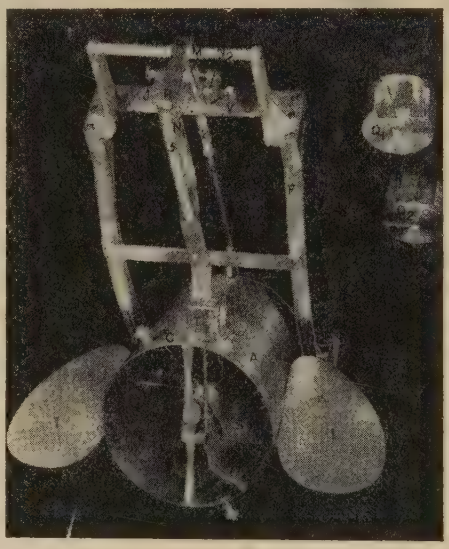

Figure 4.
Rear view of sampler taken somewhat from above. Net has been removed. Two messengers shown at right. For Key see Fig. 2.

In case a second sampler is to be used on the same cable hang two messengers from the hooks at the base of rod (P) at the same time the shutter is set. The wire from one messenger should be about 10 in. long and the loop at its upper end should be passed outside the guard rod through one slot in the base of the frame, and then slipped over the longer of the hooks when the rod (P) is rotated for the first time. The

wire from the second messenger should be about 13 in. long, passed through the other slot, and hung on the short hook when rod (P) is rotated to its final cocked position.

b) Attachment to cable

Open the hinged clamp (L), slip it around the supporting cable at the desired distance above the bottom weight, close, and tighten by means of wing nut so that clamp cannot slide on cable. Then snap the top of the frame of the sampler on to the cable by means of spring pin (J) and close the gate lock (K) around the neck of the clamp. If messengers have been hung beneath the sampler, snap these around the cable beneath the clamp being sure the wires pass outside the guard rod and that the cut-out surface of each messenger is uppermost.

Start boat forward and then lower sampler slowly into the water taking care that the tail of the net does not whip forward and become caught on the instrument or cable. If necessary a drag (such as a 6″ tin

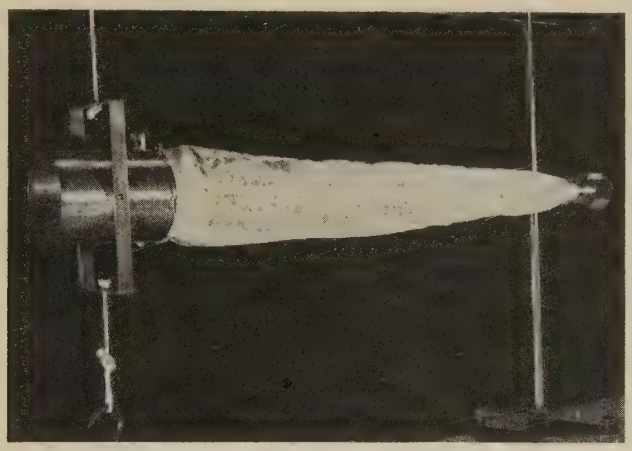

Figure 5.
Open sampler. Side view of simplified design without closing mechanism.

funnel towed spout foremost) may be attached by means of a cord to the tail of the net (Fig. 2).

When towing, a slight bend is produced in the cable where it passes over the spring pin (J), the magnitude of which depends upon the amount of horizontal resistance and the size of the weight at the end of the cable. If the messengers fail to strike the trigger (R) when the heaviest convenient weight is used, the trigger should be extended by bolting on a piece of channel brass similarly pointed.

c) Care of sampler

Keep all moving parts well lubricated. In long intervals between use dissemble cyclometer and dry parts, or flush out with kerosene and fill with oil.

If the sampler is to be used in sea water it is advisable to have all parts of the instrument nickel plated at the time of construction to prevent corrosion. Skunk oil is the best lubricant for the exposed parts of the sampler when used in sea water. After each use wash the sea water from the whole instrument especially from the cyclometer. If desired, the cyclometer may be kept full of a heavy grade of motor oil.

Discussion

Although the small size of the plankton sampler is a convenience, doubt may nevertheless arise as to whether the area of the opening is sufficient to catch reliable quantities of plankton, particularly of the larger and more active types. Tests on a statistical scale were therefore made comparing nets 5 inches in diameter with nets 12 inches and 30 inches in diameter (Winsor and Clarke, 1940)[1]. Not only was no significant difference in the variability of the catches observed with different sizes of nets but also the proportion of different species caught by the various nets did not vary in a manner to indicate differential selection with net size. Furthermore, Hardy (1926, 1939)[2] has obtained consistent results with his "continuous plankton recorder" in which the opening is only one square inch or less.

Comparison of the plankton sampler with the limnologist's "plankton trap" gave good agreement between the average of eight tows with the sampler and 34 hauls with the trap in the same area in Trout Lake, Wisconsin. One of the advantages of the sampler is that the plankton is caught over a greater distance and hence the catch is more representative in cases where irregularities in horizontal distribution of the plankton occur. A synoptic picture of the plankton of a considerable area may be obtained relatively quickly by means of a few horizontal hauls or an "oblique" haul in which the instrument is towed horizontally but the cable shortened periodically until all levels have been sampled. Accordingly, by varying the type and duration of the tow, plankton samplers may be used for an intensive study of a small area or for an extensive survey of a large region and the results placed on a quantitative basis.

Plankton samplers may be obtained from Mr. Fred Schueler, 22 Dalrymple Street, Jamaica Plain, Mass.

1 C. P. Winsor and G. L. Clarke "A statistical study of variation in the catch of plankton nets". Journal of Marine Research 3:1, 1940.
2 A. C. Hardy "The Continuous Plankton Recorder". Discovery Reports 11:457, 1936.
A. C. Hardy "Ecological Investigations with the Continuous Plankton Recorder". Hull Bulletins of Marine Ecology 1:1,1939.

Contribution No. 268

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Printed in U. S. A.

DECOMPOSITION AND REGENERATION OF NITROGENOUS ORGANIC MATTER IN SEA WATER [1]

III. Influence of Temperature and Source and Condition of Water

THEODOR VON BRAND AND NORRIS W. RAKESTRAW

(*From the Woods Hole Oceanographic Institution, Woods Hole, Mass.*)

The first two papers in this series (1937, 1939) have shown that the decomposition of suspended organic matter is accompanied by the successive formation of ammonia, nitrite and nitrate in the sea water medium in distinctly recognizable stages; that fresh diatoms can grow in the water at any stage in the cycle; and that successive cycles of decomposition and regeneration can be carried out in the same water, without the addition of new organic substrate. Since the analogous processes in the sea can scarcely be expected to take place in such simple, successive fashion, it is important to know how the decomposition cycle is influenced in rate or character by a number of variable factors. Among these are temperature, source of the sea water, and the presence or absence of such micro-organisms as can be controlled by the routine technic of sterilization. The present paper describes an experimental study of these factors.

Earlier work had shown that the nature of the decomposition cycle varied somewhat with the source of the water, being generally more rapid in water from the harbor than in that from offshore. To pursue this point further three samples of water were taken from a deep-sea station (25°–32′ N.; 53°–45′ W.): one from the surface, one from the level of the oxygen minimum (800 meters), and one from 1200 meters. Each of these samples was divided into two parts, one of which was "sterilized" by suction filtration through a No. 5 sintered-glass funnel. There were previous indications that this treatment was adequate to remove bacteria.

To each of the six portions of sea water (about two liters each) were added equal amounts of washed *Nitzschia Closterium,* which, as in

[1] Contribution No. 268 from the Woods Hole Oceanographic Institution.

previous experiments, served as a convenient source of organic matter. The suspensions were placed in the dark, at laboratory temperature, and periodically analyzed for particulate nitrogen, ammonia, nitrite and nitrate, in the manner already described. The results are shown in Fig. 1.

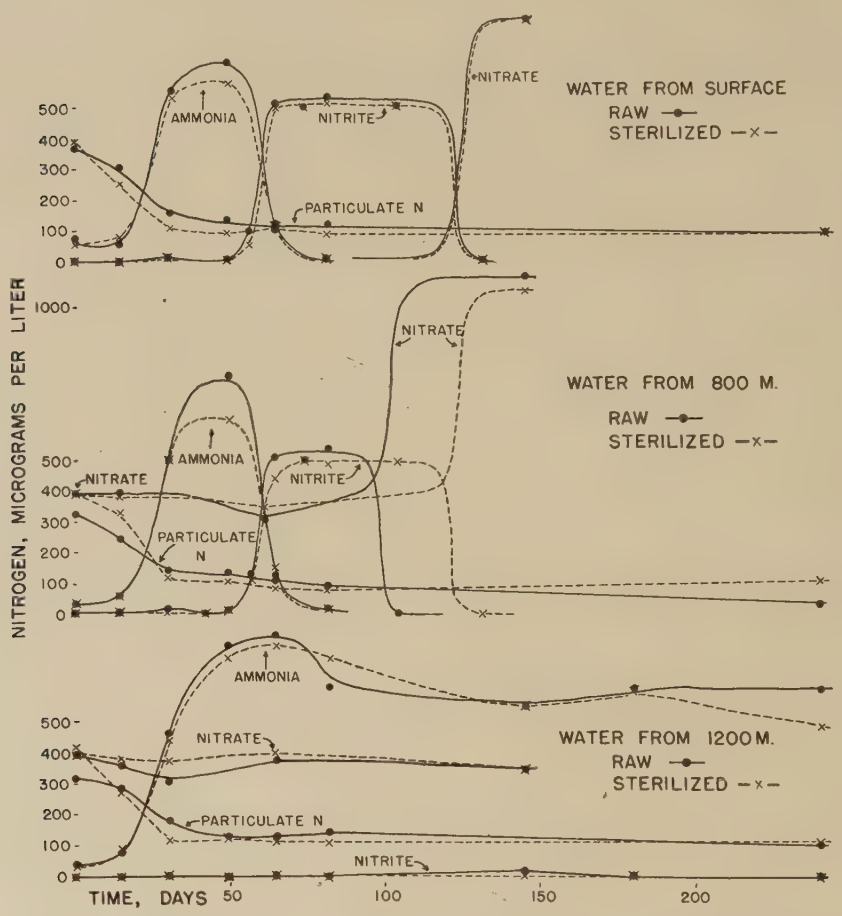

Fig. 1. The disappearance of particulate nitrogen and the simultaneous changes in ammonia, nitrite and nitrate. Fresh cultures of *Nitzschia Closterium* suspended in sea water from different depths, part of which has been sterilized by filtration.

There was no difference in the behavior of those samples which had been sterilized by filtration and those which had not. The decomposition proceeded in the normal manner in the surface water and in that from the oxygen minimum layer. But in the deep water (1200 m.)

there was no oxidation of ammonia during the time of the experiment (250 days). The nature of this inhibiting effect is yet to be determined. That it is not due simply to the absence of bacteria seems evident from the fact that such oxidation did proceed in the other samples, whether or not the water had been sterilized. This would indicate that the necessary organisms were carried by the diatoms. But since the same diatom culture was used in the deep water, the failure of oxidation to take place is evidently due to some other, unexplained factor. It should be pointed out that ammonia and nitrite are seldom found below 200 or 300 meters in the sea.

Since the oxidizing organisms seemed to be carried by the diatoms rather than in the water itself, another series of experiments was carried out in which harbor water was used as the suspension medium, part of which was sterilized by filtration, as before. To portions of the sterile and the raw water washed diatoms were added, as in the last series. To other similar portions of the water (sterile and raw) were added equal amounts of a diatom suspension which had been boiled for two minutes to sterilize it. Precautions were taken to insure the addition of equal amounts of organic matter to all four of the cultures, after which they were placed in the dark and sampled periodically, according to the usual routine. The results are shown in Fig. 2.

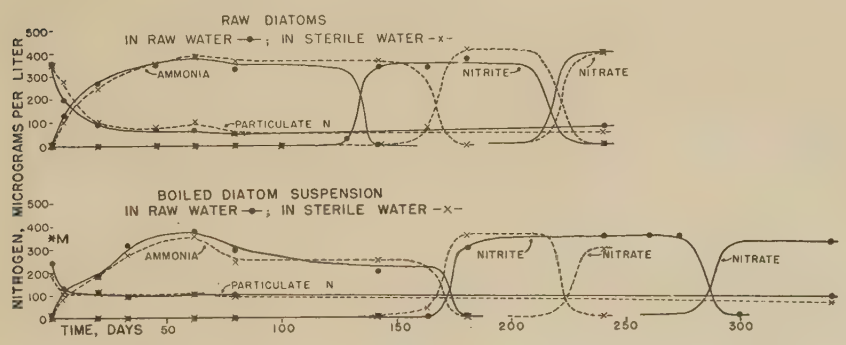

Fig. 2. The disappearance of particulate nitrogen and the simultaneous changes in ammonia, nitrite and nitrate, in harbor water, one portion sterilized by filtration. Upper curves: fresh cultures of *Nitzschia Closterium*. Lower curves: *Nitzschia* cultures boiled to sterilize. The point marked *M indicates the amount of particulate nitrogen in the *Nitzschia* culture before boiling.

The boiling of the diatom suspension quite evidently throws some of the organic matter into solution, for, although equal quantities of diatoms were used, the first determination of particulate nitrogen is much lower in the cultures to which the boiled suspensions were added than in those containing the same amount of raw diatom material. The

boiling of the diatoms also resulted in a somewhat slower rate of ammonia formation and a prolongation of the ammonia stage of the cycle.

The fact that the decomposition cycles were so nearly alike in the sterilized and the raw sea water, and that oxidation of ammonia to nitrite and nitrate took place in all cases, raises the serious question whether the filtration had actually sterilized the sea water, or whether the cultures had been contaminated with nitrite-forming organisms from the air. It is difficult to explain the formation of nitrite and nitrate except upon one of these two assumptions and we are not as yet able to resolve this difficulty. The culture methods for the identification of nitrite-forming bacteria are so unsatisfactory that we did not attempt to use them upon our material. It is almost impossible to use aseptic technic in sampling the cultures, although the chance of contamination can be diminished by pouring rather than pipetting samples.

In the effort to get further information on this point, four supposedly bacteria-free cultures of *Nitzschia* were obtained. One of these was analyzed immediately and found to be free of ammonia, nitrite and nitrate. The others were placed in the dark and analyzed later. After 145 days one culture contained 500 γ of ammonia nitrogen and 10 γ of nitrite nitrogen per liter. After 300 days the second contained 870 γ of ammonia nitrogen and 35 γ of nitrite. A large amount of suspended material still remained in both cases, but it was evident that considerable decomposition had taken place.

The last culture was opened and large numbers of bacteria were found in the remaining suspended matter. Even with great care we had not succeeded in preparing and preserving sterile cultures. Nevertheless, it seems worthwhile to note that bacteria developed only very slowly and that an almost negligible amount of ammonia had been oxidized to nitrite in 300 days. Apparently it is easier to eliminate the organisms responsible for oxidation than those which may possibly take part in the formation of ammonia.

To determine the temperature coefficient of the decomposition process, three suspensions of washed cells of *Nitzschia* were prepared in the usual manner. These were then placed in the dark at constant temperatures: one at 15° C., one at 7–9° C., and one at 1–2° C. By a stroke of good luck, when the first complete analysis was made, after 280 days, the one at the lowest temperature (No. 28) was in the ammonia stage, the one at the middle temperature (No. 29) was in the nitrite stage, and the one at the highest temperature (No. 30) had completed the cycle and all the nitrogen was in the form of nitrate. The complete results are given in Table I.

Unfortunately, No. 29 was lost at about the time when the nitrite had disappeared, but the cycle was so nearly completed at the time of the last preceding analysis that a sufficiently accurate estimate of the total elapsed time could be made. At the date of writing, after 635 days, No. 28 had not gone beyond the ammonia stage.

TABLE I

Series Nos. 28, 29 and 30. Sea water containing fresh cultures of *Nitzschia Closterium* kept in the dark at different temperatures as shown. Micrograms of nitrogen per liter.

	Date	Particulate	Ammonia	Nitrite	Nitrate
No. 28	9–14–38	470	10	0	10
Temperature	10– 3–38	260			
1 to 2° C.	1– 6–39	244			
	4–17–39	98			
	6–22–39	134	385	0	15
	8–30–39	64			
	2–26–40	24	310	0	10
	6–11–40	24	385	0	5
No. 29	9–14–38	470	10	0	10
Temperature	10– 3–38	129			
7 to 9° C.	1– 6–39	75			
	4–17–39	51			
	6–22–39	67	21	330	10
	8–30–39	41	20	320	
	9– 7–39			200	
	2–26–40	25	0	45	
No. 30	9–14–38	483	5	0	10
Temperature	10– 3–38	38			
15° C.	1– 6–39	49			
	4– 7–39	47			
	6–22–39	57	18	0	375
	8–30–39	28	25	0	400
	2–26–40	40	0	0	400
	6–11–40	18	0	0	400

The complete cycle in No. 30 (15°) took less than 280 days, and in No. 29 (7–9°) about 550 days. A temperature difference of 6 to 8° C. therefore more than doubled the velocity of the over-all process. Since more than one reaction mechanism is involved in the cycle, the relation is probably not a simple one, and it is indeed possible that a certain minimum temperature is necessary for the oxidation of ammonia.

On September 2, 1939, portions of cultures Nos. 28, 29 and 30 were inoculated with fresh diatoms and placed in the light. At this time the maximum amounts of ammonia, nitrite and nitrate, respectively, were

in these three cultures. Two weeks later there was no ammonia, nitrite or nitrate in any of the three, and an abundant diatom growth was observed. This confirms definitely our earlier observation that new diatoms can grow in the medium at any stage in the cycle of decomposition.

Summary

The source of the water is important in determining the nature of the decomposition cycle. Oxidation of ammonia to nitrite is retarded in water from the deep sea (1200 m.). Inconclusive results were obtained from efforts to sterilize both the water and the original organic matter, but it is evidently easier to eliminate organisms responsible for the oxidation processes than those which may participate in the formation of ammonia. The speed of the whole decomposition cycle was more than doubled by an increase of 6° or 8° in temperature. Growth of diatoms is possible at any stage in the cycle of decomposition.

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Contribution No. 269

REPORTS ON THE SCIENTIFIC RESULTS OF THE ATLANTIS EXPEDITIONS TO THE WEST INDIES, UNDER THE JOINT AUSPICES OF THE UNIVERSITY OF HAVANA AND HARVARD UNIVERSITY

The Brachyuran Crabs[1]

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INTRODUCTION

The collection of Brachyura taken by "Atlantis" in the Bahamas and off the coasts of Cuba in 1938 and 1939 contains 772 specimens, representing 80 distinct species. Of this number, 89 specimens belonging to 25 species are shallow water or terrestrial forms which were either gathered by members of the expedition, presented to the expedition en route by fishermen or dredged inside Cabo Cruz, Oriente Province. off the south coast of Cuba, in depths of 11½ to 28 fathoms; although most of these species are familiar West Indian forms, they are included here so that the record of the expedition may be complete. The remaining 683 specimens of 55 species were all taken with either Blake or Otter trawls from depths in excess of 100 fathoms, and all but a single specimen of a widely ranging species, which was taken in the Bahamas, came from off the coasts of Cuba. Nine of the species, all but one from deep water, were previously undescribed forms; one other, although previously known, had been confused with another species and has been redescribed under a new name; and one of these is the type of a remarkable new genus. Two of the new species have been described in a previous paper,[2] but all are here figured for the first time.

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(1) Contribution No. 269 of the Woods Hole Oceanographic Institution.
(2) Mem. Soc. Cubana Hist. Nat., vol. 13, no. 1, 1939, pp. 51-52.

In 1940, "Atlantis" made four dredging stations east of St. Augustine, Florida, which yielded 13 specimens of five species, three of which were not taken in 1938 and 1939. As some of these records are noteworthy, they are included here even though they are not strictly a part of the Cuban or Bahaman fauna. Finally, a new species of *Trizocarcinus,* taken by the "Blake" but never described, is included here in order that our knowledge of the West Indian Brachyura may be brought up to date.

With the addition of the new species taken by this expedition the truly deep-water crabs of the West Indies, that is those species which normally occur below 100 fathoms, now number about 100. Comparison with the "Blake" Expeditions in 1877-1880 and the United States Fish Commission collections made by the "Albatross" in 1884, 1885, 1886 and 1919 and by the "Fish Hawk" in 1899, 1901, 1902, 1903 and 1912, all of which ranged far more widely in the West Indies than did "Atlantis", discloses that, out of these 100 species, the "Blake" collected 57 (including the species here described for the first time), the Fish Commission dredgings yielded 67 species and, as noted above, the "Atlantis" took 55 species in 1938 and 1939 from off the coasts of Cuba alone.

That the brachyuran faunas of the north and south coasts of Cuba in similar depths are not strikingly different is illustrated by the fact that, of the 13 species taken in Bahia de Cochinos on the south coast of Matanzas Province, all but one, *Cyclodorippe agassizii,* were also found on the north coast of Cuba and 11 of them occurred off the north coasts of Santa Clara and Camaguey Provinces from Caibarien to Cayo Romano. As far as the crabs are concerned, the collections from Bahia de Cochinos proved less interesting than those from the north coasts, for only 13 species were taken from the former locality at 30 stations and only one of these belonged to a new form, the previously known but misidentified *Tetraxanthus rathbunae* which was also found to be widely distributed along the north coast. The largest and most interesting catches were made in the area at the junction of the Nicholas, Santaren and Old Bahama Channels and stretching down into the western portion of the latter channel. Although a large number of stations were concentrated in this region, particularly in 1939, the results obviously justified this expenditure of time. It might be mentioned that 100 specimens of 20 species

were taken at 18 stations off Caibarien, 220 specimens of 25 species from 28 stations off Punta Alegre and 181 specimens of 24 species from 14 stations off Cayo Coco; four of the species from off Caibarien and three each from off Punta Alegre and Cayo Coco were previously undescribed.

The bulk of this collection has been deposited in the Museum of Comparative Zoölogy, but a set of each species, wherever possible, has been sent to the Museo Poey at Havana, Cuba, and several of the more striking species to the Museum at the Bermuda Aquarium, Flatts, Bermuda.

In the systematic portion of this report reference has been made only to one of Miss Rathbun's four monographs on American crabs, unless additional citations were needed to clear up the synonymy of certain species or to bring the references to important papers up to date. Since these monographs are practically indispensable to anyone interested in the taxonomy of American Brachyura, it is felt that all such workers will have access to these volumes and, through them, can obtain references to the earlier literature.

The drawings for figures 1, 3, 5, 7, 9, 11 and 17 are the work of Mr. Eugene N. Fischer and were made possible through a grant from the Milton Fund of Harvard University. The remaining figures are by the author.

SYSTEMATIC ACCOUNT

Family RANINIDAE

Raninoides lamarcki Milne Edwards and Bouvier

Raninoides laevis var. *lamarcki* A. Milne Edwards and Bouvier, E. L., Mem. Mus. Comp. Zoöl. Harv., vol. 47, p. 299, pl. 1, figs. 8, 9; pl. 2, figs. 3,(3) 4, 1923.
Raninoides lamarcki Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 13, text-fig. 8, pl. 1, figs. 3, 4, pl. 2, fig. 3,(3) 1937.

Occurrence.

North coast of Cuba:

Off Bahia de Matanzas, Matanzas Province; station 2,999B; 145-190 fathoms; 1 small male, 2 small females (1 female with a rhizocephalan parasite).

(3) It is apparent from Milne Edwards' and Bouvier's descriptions of *R. laevis lamarcki* and *R. fossor* that figures 3 and 5 on plate 2 of that work should be interchanged. Miss Rathbun has reproduced figure 3 as the chela of *R. fossor*, whereas it is in reality that of *R. lamarcki*.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,394; 200 fathoms; 1 male.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 3,419; 180 fathoms; 2 males.

There is an additional male specimen of this species in the Museum of Comparative Zoölogy collected at Havana, Cuba, in 1937 by Dr. L. Howell Rivero.

Remarks.—All of these specimens differ from Miss Rathbun's description in having a distinct spine on the tooth on either side of the front, but this spine is not as prominent as that in *R. louisianensis* Rathbun. The three small specimens from station 2,999B agree very well with Milne Edwards' and Bouvier's description and figures; the four larger males, however, all have the dactyls of the second and third ambulatory legs appreciably narrower than in their figures. In the presence of a spine on the tooth on either side of the front and the relatively narrow dactyls of the ambulatory legs, these specimens approach *R. louisianensis* but they are otherwise distinguished from that species by having only three spines on the lower margin of the manus of the chela and no spine at the base of the mobile finger.

Lyreidus bairdii Smith

Lyreidus bairdii Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 23, pl. 5, figs. 5, 6, 1937.

Occurrence.

North coast of Cuba:

Off Puerto Tanamo, Oriente Province; station 3,374; 300 fathoms; 1 female with two rhizocephalan parasites.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,405; 235 fathoms; 1 male.

Off Santa Cruz del Norte, Havana Province; station 3,490; 250 fathoms; 1 male.

Family DROMIIDAE

Dromidia antillensis Stimpson

Dromidia antillensis Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 33, text-fig. 12, pl. 7, figs. 1-3, 1937.

Occurrence.

South coast of Cuba:

Inside Cabo Cruz, Oriente Province; stations 3,347-3,350; 13 fathoms; 1 small male.

Family HOMOLODROMIIDAE

Homolodromia paradoxa A. Milne Edwards

Homolodromia paradoxa Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 58, pl. 13, figs. 1, 2, pl. 14, figs. 1-4, 1937.

Occurrence.

North coast of Cuba:

Off Bahia de Cardenas, Matanzas Province; station 2,995; 370-605 fathoms; 1 male; station 3,474; 490 fathoms; 1 male.

Off Bahia de Nuevitas, Camaguey Province; station 3,380; 460 fathoms; 1 male.

Remarks. – The largest specimen, that from station 3,474, is considerably larger than the holotype of this species; the carapace measures 23.3 mm. in greatest length and is 18.0 mm. broad across the widest portion of the branchial regions. The two other specimens have the carapace 15.1 and 17.1 mm. long.

Dicranodromia ovata A. Milne Edwards

Dicranodromia ovata Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 60, text-fig. 15, pl. 13, figs. 3, 4, 1937.

Occurrence.

North coast of Cuba:

Off Playa Baracoa, Havana Province; station 3,303; 260 fathoms; 1 male.

Off Bahia de Matanzas, Matanzas Province; station 3,464; 200 fathoms; 1 male; station 3,485; 385 fathoms; 1 female.

Off Bahia de Cardenas. Matanzas Province; station 3,474; 490 fathoms; 1 female.

Off Caibarien, Santa Clara Province; station 3,435; 255 fathoms; 1 ovigerous female; station 3,437; 260 fathoms; 2 females (one ovigerous).

Remarks. – The four described species of *Dicranodromia, D. mahyeuxii* A. Milne Edwards from the eastern Atlantic, *D. baffini* (Alcock) from the Indian Ocean, *D. döderleini* Ortmann from Japan and the present species apparently differ from one another, aside from slight differences in the branchial formulae, only in the degree of spinulation and hairiness of the carapace. The present series of *D. ovata* shows that these characters are extremely variable. The largest specimen, the female from station 3.485 in which the carapace measures 25.5 mm. in length, is very sparsely hairy and entirely devoid of spines or spinules on the dorsal surface and lateral margins of the carapace. The ovigerous female from station 3,435 has the carapace 14.0 mm. long and is clothed in long, coarse hairs, particularly on the legs as in *D. baffini,* and also has no spines on the carapace. The three other females have the carapace from 12 to 18 mm. long, are clothed in a medium coat of hairs and have a few spines near the anterolateral margins of the carapace. The larger male, from station 3,303, has a carapace length of 11.0 mm.; it is provided with short, soft hairs and beneath them the carapace is almost completely covered dorsally with short spines very much as in *D. mahyeuxii,* a paratype of which is in the Museum of Comparative Zoölogy. The smaller male, however, has the carapace 7.0 mm. long and shows a stronger growth of hairs, but much less spinulation, there being no spines on the mid-dorsal surface of the carapace. More material of the three extra-American species must be obtained before the true diagnostic characters of these forms can be defined.

An additional small female specimen of this species was taken by "Atlantis" east of St. Augustine, Florida; 30° 58′ N., 79° 34′ W.; station 3,781; 265-290 fathoms; February 24, 1940. This specimen, which has a carapace length of about 9.5 mm., is provided with more spines on the carapace than is the male from station 3,303; in addition to countless short spines on the carapace, the edges of the rostral teeth are also armed with numerous spines. This specimen is also clothed with long, silky hairs on the carapace and legs.

Family THELXIOPEIDAE

Thelxiope barbata (Fabricius)

Thelxiope barbata Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 63, text-fig. 16, pl. 15, figs. 1, 2, 1937.

Occurrence.

North coast of Cuba:

Off Caibarien, Santa Clara Province; station 3,438; 265 fathoms; 1 male.

Thelxiope vigil (A. Milne Edwards)

Thelxiope vigil Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 66, pl. 16, figs. 1-3, 1937.

Occurrence.

North coast of Cuba:

Off Playa Baracoa, Havana Province; station 3,302; 230 fathoms; 3 males; station 3,303; 260 fathoms; 5 males.

Off Caibarien, Santa Clara Province; station 3,434; 260 fathoms; 1 male. 1 ovigerous female; station 3,437; 260 fathoms; 1 female.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,980B; 220-225 fathoms; 1 male.

South coast of Cuba:

Bahia de Cochinos, Santa Clara Province; station 3,324; 320 fathoms; 1 ovigerous female.

Remarks.—All of these specimens differ from prevoius descriptions in having the rostrum minutely bifid and in having a small, but distinct, spine on the epistome. The rostrum appears to be a single spine to the naked eye, but under the lens a distinct linear incision can be seen running back from the tip. The spine on the epistome arises from the posterior end of the longitudinal carina which passes between the basal joints of the antennules and, although much smaller than the corresponding spine in *T. barbata*, it is quite apparent even to the naked eye.

Homologenus rostratus (A. Milne Edwards)

Homologenus rostratus Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 70, text-fig. 17, pl. 17, figs. 1-3, 1937.

Occurrence.

North coast of Cuba:

Off Playa Baracoa, Havana Province; station 3,305; 330 fathoms; 1 female.

Off Bahia de Cardenas, Matanzas Province; station 2,995; 370-605 fathoms; 1 male, 3 females (2 ovigerous); station 2,996; 470-665 fathoms; 1 female.

Nicholas Channel off Bahia de Santa Clara, Santa Clara Province; station 3 458; 535 fathoms; 1 ovigerous female; station 3,459; 500 fathoms; 1 ovigerous female.

South coast of Cuba:

Windward Passage, south of Oriente Province; station 3,357; 875 fathoms; 1 ovigerous female.

Family LATREILLIIDAE

Latreillia elegans Roux

Latreillia elegans Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 73, text-fig. 18, pls. 20, 21, 1937.

Occurrence.

North coast of Cuba:

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,396; 180 fathoms; 1 male.

Family DORIPPIDAE

Ethusa microphthalma Smith

Ethusa microphthalma Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 82, pl. 22, fig. 3, pl. 23, fig. 3, 1937.

Occurrence.

North coast of Cuba:

Off Bahia Cardenas, Matanzas Province; station 3,476; 360 fathoms; 1 female.

Off Caibarien, Santa Clara Province; station 3,421; 235 fathoms; 1 male; station 3.432; 250 fathoms; 1 male.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,982D; 150-180 fathoms; 1 male; station 3,411; 260 fathoms; 1 female; station 3,413; 215 fathoms; 1 female; station 3,417; 200 fathoms; 1 male, 1 female; station 3,419; 180 fathoms; 1 male, 1 female.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,392; 225 fathoms; 1 male; station 3,393; 220 fathoms; 1 male; station 3,394; 200 fathoms; 1 male; station 3,396; 180 fathoms; 1 female; station 3,404; 215 fathoms; 1 female.

Old Bahama Channel off west end of Cayo Romano, Camaguey Province; station 3,386; 220 fathoms; 1 male, 1 female; station 3,387; 245 fathoms; 1 female.

Off Puerto Tanamo, Oriente Province; station 3,374; 300 fathoms; 1 female; station 3,376; 285 fathoms; 1 male.

South coast of Cuba:

Bahia de Cochinos, Santa Clara Province; station 2,963; 190-180 fathoms; 1 male; station 3,320; 185 fathoms; 1 female.

Remarks.—All of the specimens in the present collection differ from Miss Rathbun's description in that the spiniform anterolateral, or extraorbital, angles do not reach quite as far forward as the frontal spines and in no case do they extend beyond the front. In the smaller specimens, 12 mm. or less in carapace length, the distance between the anterolateral angles is considerably greater than half the greatest width of the carapace, and the latter is frequently slightly longer than broad; these last two differences are much more noticeable in male than in female specimens.

Ethusa tenuipes Rathbun

Ethusa tenuipes Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 87, pl. 24, fig. 3, pl. 25, fig. 3, 1937.

Occurrence.

North coast of Cuba:

Off Bahia de Matanzas, Matanzas Province; station 3,482; 190 fathoms; 1 male.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,391; 220 fathoms; 1 male.

South coast of Cuba:

Bahia de Cochinos, Santa Clara Province; station 3,320; 185 fathoms; 1 ovigerous female.

Cymonomus caecus, sp. nov.
(Figs. 1, 2)

Holotype. – Female, M. C. Z. No. 10,705; off Bahia de Nuevitas, Camaguey Province, Cuba; lat. 21° 34′ N., long. 76° 59′ W.; 460 fathoms; April 25, 1939; station 3,380.

Description. – Carapace more or less sharply quadrate. It is paved with low, miliary granules and marked by short, faint furrows separating the hepatic region from the anterior gastric region and from the branchial region and by a pair of much deeper and broader depressions bordering the cardiac and intestinal regions. Facial region advanced slightly beyond level of anterolateral margins and sharply marked off from them by the rather prominent antennal scales. Rostrum short, narrowly triangular and unarmed except for a few setae; it is about half as long as the eyestalks. Eyestalks reaching about to middle of second segment of antennules, narrowly tapering,

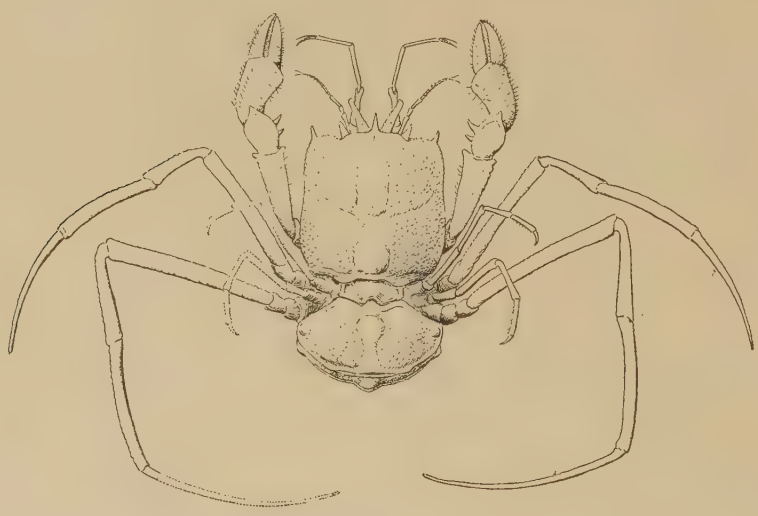


Fig. 1

Cymonomus caecus. Holotype. × 4.

armed with sharp granules on the inner margin and lacking any vestige of a true cornea. Antennular peduncle longer than carapace and rostrum combined; second segment subequal to fourth, swollen at base and armed with a few sharp granules on the outer margin. Third segment longer than second or fourth. Antennal peduncle reaching scarcely to end of second segment of antennular peduncle; antennal scale prominent with a few small spines on outer margin.

Exopod of outer maxillipeds extending beyond endopod; merus subequal to ischium and extending far beyond the insertion of the palp. Chelipeds with one or two spines on inner margin of carpus; movable finger distinctly longer than palm. Chelipeds and walking legs finely granular and sparsely hairy. Dactyl of first ambulatory leg as long as propodus and three-fourths of carpus; dactyl of second ambulatory leg nearly as long as propodus and carpus combined. Last two pairs of legs end in a curved dactyl. Sternum and abdomen finely granular; female abdomen composed of six somites; telson with very faintly concave margin.

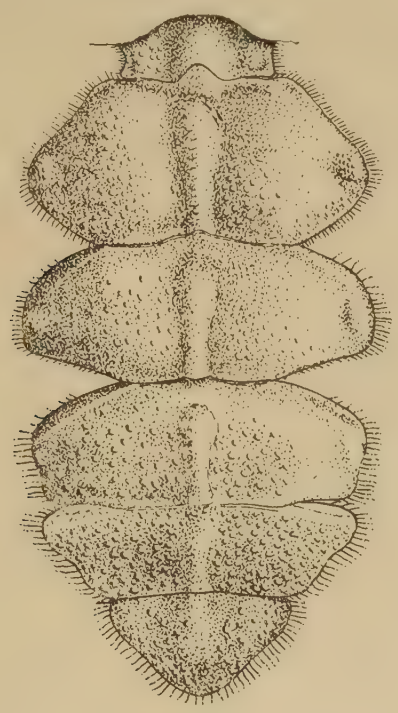


FIG. 2
Cymonomus caecus
Abdomen of holotype female × 10.

Measurements. – Length of carapace plus rostrum 5.4 mm. length of rostrum 0.7 mm., breadth of carapace 5.2 mm., length of eyestalk 1.5 mm.

Remarks. – This species belongs to the *quadratus* group of the genus and differs but little from *C. quadratus* A. Milne Edwards, 1880. Examination of the series of specimens of that species in the

Museum of Comparative Zoölogy discloses that it is a very variable one, particularly as regards the shape and armature of the carapace, but *C. caecus* apparently differs from it in two characters which are reassonably constant: the long, slender and nearly straight eyestalks and the shorter antennal peduncles which do not reach beyond the second segment of the antennular peduncle.

Cymonomus rostratus, sp. nov.

(Figs. 3, 4)

Holotype. – Female, M. C. Z. No. 10,706 off Bahia Cardenas, Matanzas Province, Cuba; lat. 23° 18′ 30″ N., long. 80° 52′ W.; 360 fathoms; May 10, 1939; station 3.476.

Allotype. – A male from the same station.

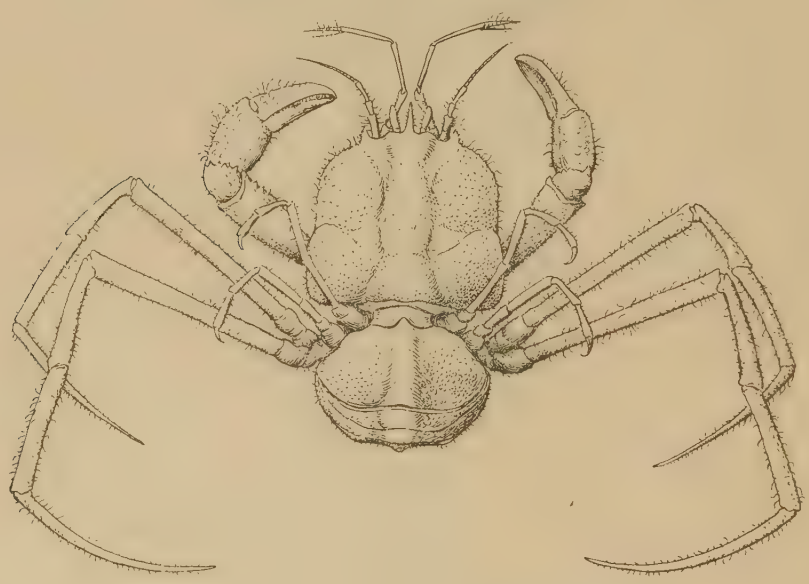


Fig. 3
Cymonomus rostratus. Holotype. × 4.

Description. – Carapace distinctly broader posteriorly than anteriorly and curving in gradually in front to the orbits. The surface is covered with small, sharp granules which are slightly larger on the anterolateral portions, but there are no true spines. There is a deep groove on either side of the cardiac and intestinal regions and at the anterior ends of these a shallower, somewhat semicircular

furrow traverses each branchial region; these transverse furrows are more prominent in the female than in the male. Facial region well advanced beyond level of anterolateral margins. Rostrum narrowly triangular. unarmed except for some long setae and extending beyond the eyestalks. Eyestalks slender, slightly curved inward and armed on the inner margin with six or seven sharp spines; the eyestalks reach to the middle of the second joint of the antennular peduncle where they terminate in a minute. colorless vestige of the cornea.

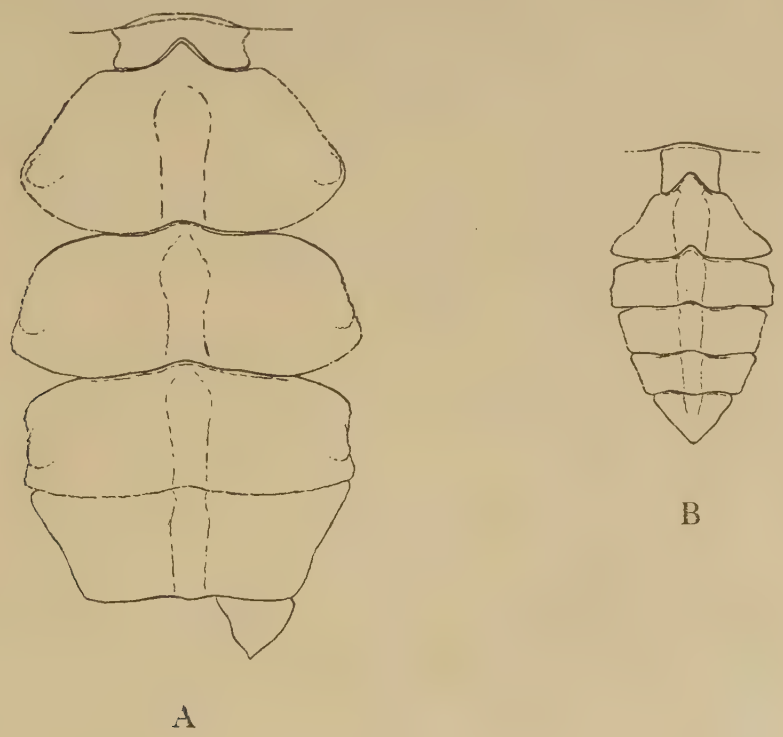


FIG. 4

Cymonomus rostratus

A. Abdomen of holotype female. × 8.
B. Abdomen of allotype male. × 8.

Antennular peduncle as long as the carapace and half of the rostrum; second segment subequal to the fourth and shorter than the third, slightly swollen at the base and armed on outer margin with some minute serrations. In the male the antennular peduncles are considerably longer than the carapace and rostrum. Antennal peduncle extending beyond second segment of antennular peduncle by about half the length of its terminal joint. Antennal scale rather

prominent and armed with a few spines on the outer margin. Exopod of outer maxillipeds reaching about as far as endopod; merus about as long as ischium and extending far beyond insertion of palp, the distal portion being noticeably narrowed. Chelipeds with from one to three spines on inner margin or carpus; movable finger distinctly longer than palm and with several dorsal spines proximally. Chelipeds and following legs finely granular and covered with short hairs. Dactyl of first ambulatory leg as long as propodus and three-fourths of carpus; dactyl of second ambulatory leg as long as propodus and four-fifths of carpus. Last two pairs of legs end in a curved dactyl. Sternum and abdomen covered with scattered fine granules. Both male and female abdomens are composed of six somites. The telson of the female is damaged, but the margins are apparently slightly concave.

Measurements. – Female holotype, total length of carapace and rostrum 7.2 mm., length of rostrum 1.3 mm., greatest breadth of carapace 6.8 mm., length of eyestalk 1.2 mm. In the male paratype the rostrum is broken. but the specimen is slightly smaller than the female, having the carapace 6.2 mm. wide.

Remarks. – *C. rostratus* is superficially very like *C. andamanensis* Alcock, 1905, due to the similarity in the form of the carapace, but the more slender eyestalks and much longer rostrum distinguish the Cuban species at a glance.

Cymonomus cubensis, sp. nov.

(Figs. 5, 6)

Holotype. – Female, M. C. Z. No. 10,708; northwest of Cabo San Antonio. Pinar del Rio Province, Cuba; lat. 22° 02′ 30″ N., long. 85° 06′ W.; 550 fathoms; March 25. 1939; station 3,313.

Paratype. – One ovigerous female; off Caibarien, Santa Clara Province, Cuba; lat. 23° 10′ N., long. 79° 35′ W.; 260 fathoms; May 1, 1939; station 3,434.

Additional specimens. – One ovigerous female from Nicholas Channel off Puerto Sagua la Grande, Santa Clara Province, Cuba; 415 fathoms; station 3.990A.

One male from off Bahia de Matanzas, Matanzas Province, Cuba; 425 fathoms; station 3,469.

Description. – Carapace quadrate, finely granulate, unarmed and with a short pubescence, cardiac and intestinal regions bordered by broad depressions and a somewhat semicircular furrow crosses each branchial region. Facial region little advanced beyond line of antero-

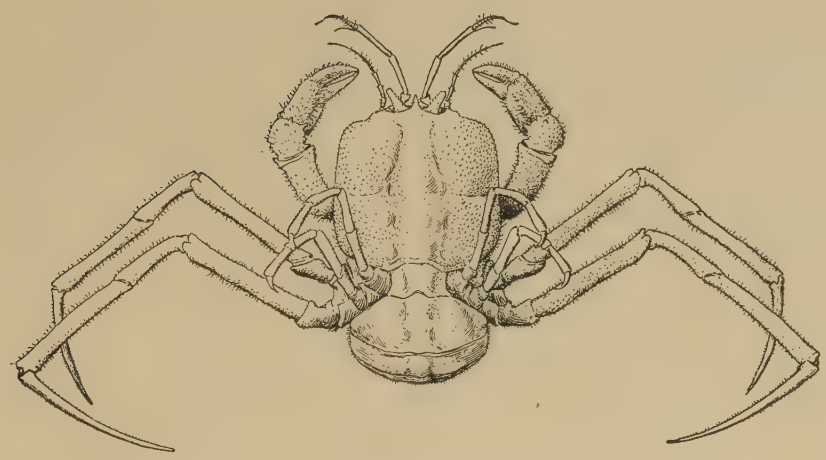


FIG. 5
Cymonomus cubensis. Holotype. × 2.

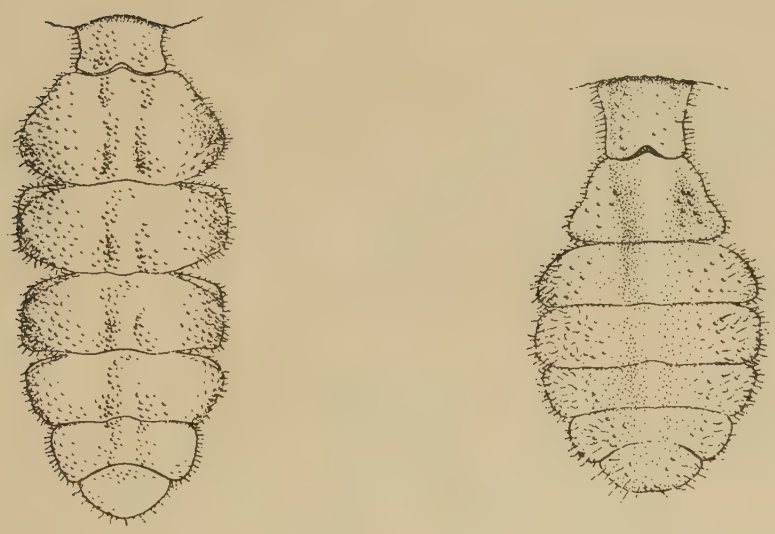


FIG. 6
Cymonomus cubensis

A. Abdomen of holotype female. × 8.
B. Abdomen of male from station 3,469. × 16.

lateral margins. Rostrum short, triangular and bearing a few small spines on its margins; it reaches about half as far as the eyestalks. Eyestalks rather broad at base and tapering more sharply than in the two preceding species; they are nearly straight, armed with prominent spines, those on the inner margins being larger and more numerous than those on the outer surface, and extend nearly as far as the middle of the second segment of the antennular peduncle where they terminate in a convex. colorless tip which bears but little resemblance to a cornea. Antennular peduncle very variable; in the holotype it is robust, much shorter than the length of the carapace; in the paratype it is definitely longer than the carapace and much more slender, particularly as regards the last two segments; there are a few minute serrations on the outer margin of the first segment. Antennal peduncle extending beyond second antennular segment by most of the length of its terminal joint. Antennal scale small armed with a few outer spines and largely hidden from dorsal view by the antenna. Exopod of outer maxilliped not reaching as far as merus of endopod; merus spiny, about as long as ischium and extending well beyond insertion of palp. Chelipeds with from two to four spines on inner margin of carpus; movable finger distinctly longer than palm. Chelipeds and following legs covered with sharp granules among which are scattered some larger granules or short spines. Dactyl of first ambulatory leg as long as propodus and one-half of carpus; dactyl of second ambulatory as long as propodus and three-fifths of carpus. Last two pairs of legs end in curved dactyls. Sternum and abdomen finely granulate. Abdomen composed of seven free somites; telson of female evenly convex.

Measurements. – Female holotype, length of carapace plus rostrum 12.1 mm., length of rostrum 1.1 mm., breadth of carapace 11.8 mm., length of eyestalk 2.2 mm. The eggs of the paratype are about 1.0 mm. in diameter.

Remarks. – Except for its much larger size, this form is very similar to *C. quadratus* A. Milne Edwards, 1880. The only apparent differences are the somewhat straighter and more robust eyestalks, the shorter exopod of the outer maxilliped and the extra abdominal somite. This is the first species of *Cymonomus* to be described as having seven abdominal somites. but this character is omitted from the description of several of the known species. Although this point would normally be of much more than specific importance, the species is so closely allied to *C. quadratus* in all other features that it seems best for the present not to remove it from the genus, *Cymonomus*. It apparently forms a link between *Cymonomus* and *Cymopolus* together with *Cymopolus agassizii* A. Milne Edwards and Bouvier, 1899.

The male from station 3,469 and the ovigerous female from station 2,990-A agree with the type specimens in every particular except that the rostrum is missing. This naturally gives the specimens the appearance of *C. normani* Lankester, 1903, but since this is the only difference, it is probably best to assume that the rostrum has been accidentally lost in these specimens. The male is much smaller than the three females, the carapace measuring only 4.9 mm. in length and so approachng *C. quadratus* in size, but as in the females the abdomen is made up of seven distinct segments.

Cyclodorippe agassizii A. Milne Edwards

Cyclodorippe agassizii Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 105, text-fig. 25, pl. 32, figs. 5, 6, 1937.

Occurrence.

South coast of Cuba:

Bahia de Cochinos, Santa Clara Province; station 2,960; 270 fathoms; 1 small male; station 3,330; 230-265 fathoms; 1 male.

Remarks. – The male from station 3,330 agrees very well with the holotype of *C. agassizii* with which it has been compared, except that the spines on the protogastric regions of the carapace are somewhat more pronounced and the frontal and lateral areas of the carapace and, particularly, the chelipeds are fringed with long hairs. In the young male from station 2,960 the dorsal protuberances of the carapace are but little larger than in *C. antennaria* but the form of the front and orbits leave little doubt that it belongs to *C. agassizii*.

Cyclodorippe ornata, sp. nov.

(Figs 7, 8)

Holotype. – Ovigerous female, M. C. Z. No. 10,712; off Bahia de Matanzas, Matanzas Province, Cuba; lat. 23° 09′ N., long. 81° 27′30″ W.; 240 fathoms; May 11, 1939; station 3,478.

Paratypes. – One male, three females (two ovigerous); Old Bahama Channel off Punta Alegre, Camaguey Province, Cuba; lat. 22° 47′ N., long. 78° 48′ 30″ W.; 205-230 fathmos; March 11, 1938; station 2,982B.

Description. – Carapace subcircular and covered with granules which are larger and more prominent laterally. Front broad, deeply concave dorsally, angulate at the junction with the orbital margin and with a broad, median incision at the tip in dorsal view; margin

of front denticulate with two or three small fissures in each lateral lobe dividing each portion into three or four low lobes. Upper margin of orbit smooth, short and curved obliquely forward where it ends in a strong, blunt-tipped spine. A large, blunt-tipped spine above lateral margin at about widest point of carapace. Metagastric spine

Fig. 7
Cyclodorippe ornata. Holtoype. × 4.

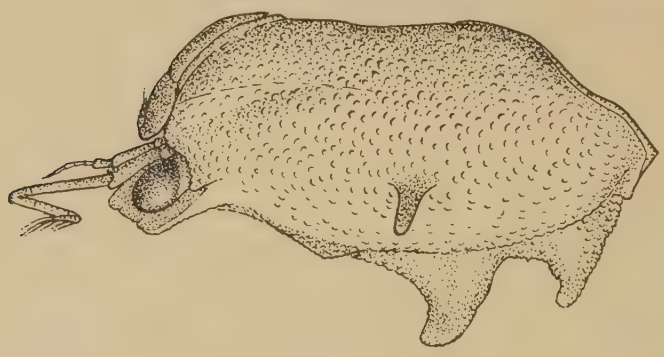


Fig. 8
Cyclodorippe ornata
Lateral view of carapace of holotype. × 10.

large, broadened in an antero-posterior plane and curved forward. Cardiac spine somewhat smaller than metagastric, also curved slightly forward, but not so broad in lateral view. Protogastric prominences

elevated, convex, or occasionally, conical. Ocular peduncles robust, the cornea exceeding half the length of the stalk. Antennular peduncles little more than half as long as carapace; basal article robust with minute serrations on its outer edge. Antennae small, the peduncle exceeding the basal article of antennular peduncle by the length of its terminal segment. Exopod of outer maxilliped fully as broad as ischium and extending beyond it; merus broadly rounded. Chelipeds well developed; chela coarsely granulate, movable finger much longer than palm; carpus granulous, with an inner spinulous lobe but without anl prominent outer tooth as in *C. bouvieri* Rathbun, 1934. Ambulatory legs nearly smooth; the first exceeds the cheliped by about the length of the dactyl and the second surpasses the first by a similar length. Last two pairs of legs very slender.

Measurements. – Female holotype, length of carapace 6.9, width 7.7 mm. Male paratype, length 5.8, width 5.9 mm.

Remarks. – These five specimens are remarkably uniform in form, the only differences being that the protogastric prominences are slightly more conical in some than in others. The species differs from the known American species of the genus in the shorter antennules, notched front and the form of the metagastric spine. It is most closely allied to *C. agassizii* A. Milne Edwards, 1880, and *C. bouvieri* Rathbun, 1934, but it differs from the first in the very different form of the orbit and from the second in the differently formed front and the absence of any distinct spine on the outer margin of the carpus of the cheliped.

Simodoríppe,[4] gen. nov.

Carapace with subparallel lateral margins which are rounded anteriorly and posteriorly. Posterior gastric, cardiac and intestinal regions well-defined. Frontal region with a sharp dorsal inclination and separated from the remainder of the carapace bya constriction Orbits tubular in appearance and with a deep dorsal notch. Eyestalks slender and movable, with a pigmented cornea. Rostrum absent, represented by a pair of minute lobes separated by a median incision. Antennules long, protruding from the orbit when folded; the peduncle of the antenna does not form a protective valve. Buccal cavern ovoid and completely covered by the external maxillipeds which extend quite to the frontal margin and cover the confluent efferent branchial canals. The palp of the external maxillipeds is articulated near the center of the inner surface of the merus, and the latter extends far beyond this articulation. The exognath reaches as far as the ischium

(4) σιμός (snub-nosed) + *Dorippe.*

of the endognath. Anterior and intermediate maxillipeds lack a flagellum on the exopods. There are no afferent branchial openings in front of the bases of the chelipeds. The female sexual openings are situated in the coxae of the second ambulatory legs. Chelipeds equal. First two pairs of ambulatory legs little compressed; last two pairs as in *Cyclodorippe*. The abdomen is composed of six segments in both the male and female, but the last two segments in the male are fused. The male abdomen reaches to the posterior part of the third sternite, the female to the posterior part of the second.

This genus appears to be most closely related to *Clythrocerus* as evidenced by the form of the front, the form of the buccal cavern, all of the maxillipeds, those of the anterior and intermediatte pairs being very similar to the corresponding organs in that genus. and the form of the abdomen. It differs from that genus in its larger size, differently shaped carapace, much longer antennules and the absence of a valvular cover formed by the antennal peduncle. In these latter characters the genus approaches *Cyclodorippe*.

Simodorippe tylota,[5] sp. nov.

(Figs. 9, 10)

Holotype. – Male, M. C. Z. No. 10.703; Old Bahama Channel off Cayo Coco, Camaguey Province, Cuba; lat 22° 34′ N., long. 78° 14′ W.; 220 fathoms; April 27, 1939; station 3,391.

Paratypes. – Two females, one of which is ovigerous, from the same general locality and depth; station 3,393.

Description. – Carapace with subparallel sides which become rounded and converge anteriorly and posteriorly. The posterior part of the gastric region and the cardiac and intestinal regions are depressed somewhat below the general level of the carapace and bounded laterally by wellmarked furrows. The entire surface of the carapace is covered with coarse granules among which are scattered prominent knob-like or capitate spines; four of these form a diamond on either side of the gastric region, there is a diagonal row of three across each posterior branchial region and several are clustered on the margins of the hepatic region. Orbits slanting sharply upward and cut off from the posterior part of the carapace by a sharp constriction. Around the orbit are four knob-like spines, a large dorsal one and three smaller ones of which two are lateral and one ventral. Eyes cylindrical, pigmented and movable; they do not extend beyond the lateral projections of the orbit but are plainly visible in dorsal view due to the gaping fissure between the dorsal and lateral projections of the orbit. Front depressed below the level

(5) τυλωτός (knobbed).

of the orbits and marked by two minute, concave teeth separated by a median fissure and bounded on either side by a large knob; from this knob, the frontal margin curves regularly outward and upward to the dorsal prominence of the orbit. Antennules long, about two-thirds the length of the carapace; the first segment is broad, the two

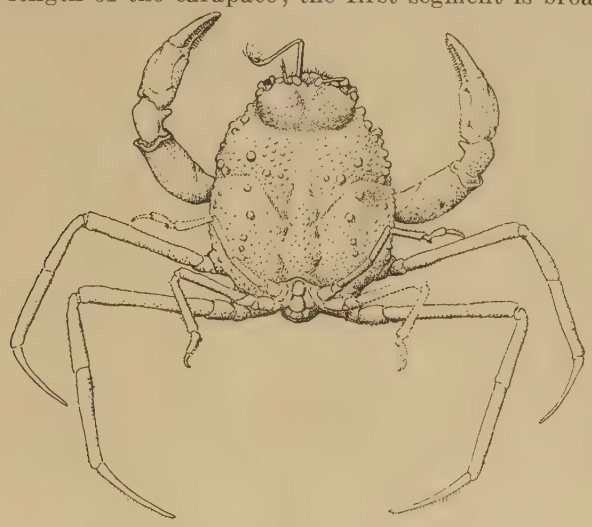


FIG. 9
Simodorippe tylota. × 2.

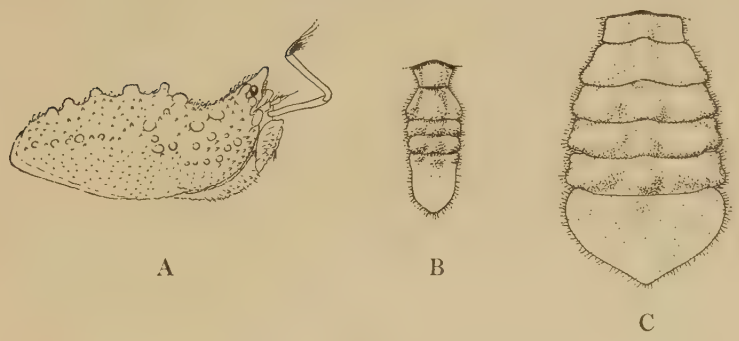


FIG. 10
Simodorippe tylota
A. Lateral view of carapace of holotype. × 3.
B. Abdomen of holotype male. × 3.
C. Abdomen of paratype ovigerous female. × 3.

following articles slender, the third slightly longer than the second, and the flagellum reduced. Despite their length, the antennules are capable of being folded into the orbito-antennal cavity, although when so folded they protrude beyond the eye and are easily seen in dorsal

view. Antennae small, barely reaching to the extremity of the second segment of the antennules; the peduncle bears a few spines but does not form a valvular process to cover the folded antennules. Outer maxillipeds long, covering the basal joint of the antennules and visible in dorsal view due to the shallow front and upturned frontal regions; the exopod reaches quite as far as the ischium and the merus extends well beyond the point of insertion of the palp. Chelipeds robust in the male, equal; the carpus has a strong inner tooth and a faint carina on the dorsal surface; palm with a tooth directed inward from the middle of the upper margin; fingers bent inward at the tips and about one third again as long as the palm. In the female, the chelipeds are more slender and the fingers twice as long as the palm. The chelipeds and all of the legs are finely granular. The first ambulatory leg extends beyond the cheliped by the length of the dactyl and the second surpasse the first by half the length of the dactyl. The dactyls of both of these legs are furred on the anterior and dorsal surfaces. The last two legs, when extended, reach slightly beyond the merus of the second ambulatory; the propodites are arched and bear a furred protuberance near the base against which the tip of the dactyl closes. Sternum finely granulate like the legs. Male abdomen composed of five movable segments, the last two being fused; in the female there are six free segments, the terminal one being large and broad. The eggs are about 0.7 mm. in diameter and numerous.

Measurements. – Male holotype, length of carapace 11.1 mm., width, not including spines. 11.7 mm. Ovigerous female, length of carapace 11.8 mm., width 12.6 mm.

Family LEUCOSIIDAE

Myropsis quinquespinosa Stimpson

Myropsis quinquespinosa Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 164, pl. 46, figs. 1-3, 1937.

Occurrence.

Bahamas:

Eight miles NE. of Great Isaac Island, Bimini Group; station 2,951; 155 fathoms; 1 male, 1 ovigerous female.

North coast of Cuba:

Off Caibarien, Santa Clara Province; station 3,421; 235 fathoms; 2 immature specimens; station 3.422; 235 fathoms; 1 male, 1 female, 1 young; station 3,423; 245

fathoms; 1 ovigerous female, 3 immature specimens; station 3,427; 240 fathoms; 1 male, 1 young; station 3.428; 240 fathoms; 2 females (1 ovigerous), 2 young; station 3,432; 250 fathoms; 2 young; station 3,435; 255 fathoms; 1 male.

Western end of Old Bahama Channel; station 2,983; 235-260 fathoms; 1 young female. 1 immature specimen; station 2,984; 240-250 fathoms; 1 young.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,982; 210 fathoms; 1 immature specimen; station 2,982A; 210 fathoms; 3 young; station 2,982C; 195-225 fathoms; 1 young; station 2,982D; 150-180 fathoms; 1 ovigerous female, 1 young; station 2,982E; 150-180 fathoms; 1 male; station 3,407; 200 fathoms; 1 immature female; station 3,410; 260 fathoms; 1 immature specimen; station 3.411; 260 fathoms; 2 immature specimens; station 3,412; 235 fathoms; 1 male; station 3,413; 235 fathoms; 1 chela; station 3,414; 230 fathoms; 1 immature specimen; station 3,415; 210 fathoms; 1 male; station 3,416; 200 fathoms; 2 males, 1 female, 3 immature specimens; station 3,417; 200 fathoms; 1 ovigerous female, 2 young; station 3,419; 180 fathoms; 1 immature specimen.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,391; 220 fathoms; 3 young; station 3,392; 225 fathoms; 1 young; station 3,393; 220 fathoms; 4 young; station 3,394; 200 fathoms; 2 young; station 3,397; 180 fathoms; 1 young; station 3,400; 180 fathoms; 2 young; station 3.401; 235 fathoms; 1 young; station 3,403; 210 fathoms; 1 male, 3 young; station 3,404; 215 fathoms; 1 young.

Old Bahama Channel off western end of Cayo Romano, Camaguey Province; station 3,387; 245 fathoms; 1 young; station 3,389; 220 fathoms; 2 young.

Off Puerto Tanamo, Oriente Province; station 3,376; 285 fathoms; 1 male, 1 young female.

South coast of Cuba:

Bahia de Cochinos, Santa Clara Province; station 2.962B; 180-190 fathoms; 1 male; 1 young; station 3,328; 260-275 fathoms; 1 male, 1 female; station 3,331; 230-260 fathoms; 1 immature specimen; station 3,332; 175-225 fathoms; 2 young; station 3,334; 185-195 fathoms; 1 immature specimen; station 3,335; 200 fathoms; 1 young.

Family CALAPPIDAE

Calappa flammea (Herbst)

Calappa flammea Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 198, pl. 59, figs. 1, 2; pl. 60, fig. 1, 1937.

Two large males of this familiar species were taken one-half mile off Cat Cay, Bimini Group, Bahamas, in eight fathoms, May 21, 1939. The larger specimen has the carapace 87.7 mm. long. 118.2 mm. broad at the sinus in front of the wings and about 138 mm. in extreme breadth.

Acanthocarpus alexandri Stimpson

Acanthocarpus alexandri Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 221, pl. 69, figs. 1, 2, 1937.

Occurrence.

North coast of Cuba:

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,982; 210 fathoms; 1 male; station 2,982E; 150-180 fathoms; 1 male; station 3,411; 260 fathoms; 2 males, 1 young; station 3,415; 210 fathoms; 1 male, 1 female.

Off Puerto Tanamo, Oriente Province; station 3,375; 230 fathoms; 2 young females.

Remarks.—All of these specimens differ from the measurements given by Miss Rathbun in having the carapace slightly, but distinctly, broader than long. The largest male has the carapace 41.0 mm. long and 42.2 mm. broad and in the largest female these measurements are 39.0 and 41.0 mm. respectively.

Paracycloïs atlantis Chace
(Figs. 11, 12)

Paracycloïs atlantis Chace, F. A., Mem. Soc. Cubana Hist. Nat., vol. 13, no. 1, p. 51, 1939.

Occurrence.

North coast of Cuba:

Off Caibarien, Santa Clara Province; station 3,420; 190 fathoms; 2 small females; station 3,422; 235 fathoms; 1 male, 1 female (soft shell).

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,982E; 150-180 fathoms; holotype female; station 3,419; 180 fathoms; 1 male, 1 female, 1 young.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,396; 180 fathoms; 2 young; station 3,397; 180 fathoms; 2 young; station 3,399; 180 fathoms; 1 female; station 3,403; 210 fathoms; 1 male, 1 female.

Old Bahama Channel off west end of Cayo Romano, Camaguey Province; station 3,390; 180 fathoms; 1 young.

Fig. 11
Paracycloïs atlantis. Male from station 3,422. × 0.7.

Description. – Carapace convex longitudinally and from side to side except across posterior part where postero-lateral wings occur. The surface is minutely granular and coarsely punctate except on extreme posterior portion where punctae disappear and the granules become larger. The surface is also uneven the elevations rougthy

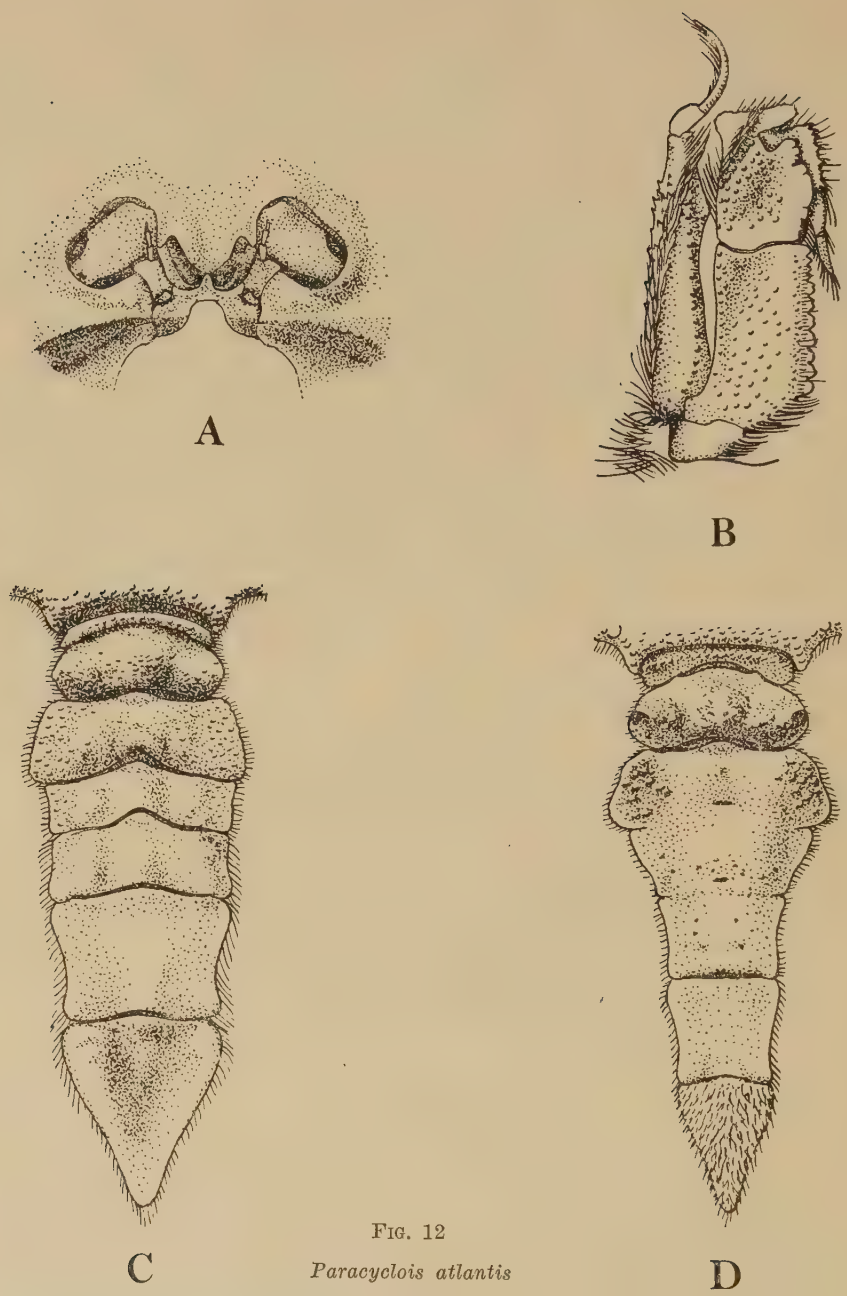


FIG. 12

Paracyclois atlantis

A. Frontal region of holotype. × 2. – B. Outer maxilliped of holotype. × 3. C. Abdomen of holotype female. × 2. – D. Abdomen of male from station 3,422. × 2.

falling into five longitudinal rows as in *Acanthocarpus*. The pair of furrows bordering the median elevation are by far the deepest depressions. The postero-lateral wings are formed by four large and one or two rudimentary spines, one rudimentary tooth often being present between the two anterior larger ones; the next to the posterior tooth is always the largest of the four, and in the young this tooth is very much larger than the other three. The posterior margin is trilobate in dorsal view, the lateral lobes being prolonged ventrally on either side of the first segment of the abdomen. The anterolateral line bears two indistinct teeth back of the orbit. The orbit has a single dorsal fissure and the orbital margin is ciliated. Front deflexed so that the tip is invisible in dorsal view, very slightly wider than the greatest diameter of the orbit and trilobate, the median lobe being rounded triangular and the lateral lobes very narrow and traversed by a shallow notch which separates the front from the orbits. The pterygostomian region below the orbits is smooth and concave, but the notch opening from this depressed area at the base of the antennae is minute.

The subdistal crest of the merus of the chelipeds is armed with five denticulate teeth. Hand surmounted dorsally by seven closely set teeth and with a row of about ten tubercles extending from the base of the dactyl to the postero-inferior angle. Between the dorsal teeth and the ventral row of tubercles are about 15 scattered tubercles on the outer surface. The inner surface of the fingers and the lower two-thirds of the inner surface of the hand, as well as the anterior margin of the merus, are heavily furred in the male, sparsely so in the female. There is a stridulating ridge behind the base of the dactyl composed of about 90 closely placed oblique striae. The ambulatory legs are smooth and polished; the merus of each leg is provided with a row of nine or ten small teeth on the lower margin and the propodus is cristate on both edges.

Outer maxillipeds with the ischium much longer than the merus. The latter is deeply, but narrowly, incised at the insertion of the palp and is produced laterally at the antero-external angle. The surface of the outer maxillipeds is granular and more or less hairy; there is a line of hairs running obliquely along the exopod and extending across the antero-external angle of the merus and the proximal portion of the ischum is more or less furred.

The sternum is coarsely tuberculate and more or less hairy anteriorly, this furriness extending onto the terminal abdominal somite in the male. In both sexes the first three segments of the abdomen are granulate and the second is sharply trilobate. In the female all of the abdominal somites are distinct; in the male, the third to fifth are fused.

Measurements. – Holotype female, length of carapace 45.5 mm.; width 49.1 mm. Male, station 3,422, length of carapace 50.0 mm.; width 55.2 mm.

Remarks. – The greater proportionate breadth of the carapace, form of the front, narrower notch on the merus of the outer maxillipeds, position and denticulate form of the subdistal crest of the merus of the chelipeds and the presence of ventral teeth on the merus of all of the ambulatory legs serve to distinguish this species from *P. milne-edwardsii* Miers, 1886, from off the Admiralty Islands. The completely deflexed front and smaller posterolateral spines on the carapace separate it from the subfossil *P. grandispinis* Etheridge and McCulloch, 1916, from Melbourne, Australia.

There is little doubt that Paracycloïs is very closely allied to *Acanthocarpus*.

Hepatus princeps (Herbst)

Hepatus princeps Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 235, pl. 70, figs. 1, 2, 1937.

Four males and seven females of this species were taken at Cienfuegos, Santa Clara Province, Cuba, in a fish trap set at the dock in four fathoms, March 30 and April 3, 1939. One male and one female were taken at Bahia de Guantanamo, Oriente Province, also from a fish trap set at the dock, April 14, 1939.

Family PORTUNIDAE

Bathynectes superba (Costa)

Bathynectes superba Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 28, pls. 9, 10, 1930.

Occurrence.

North coast of Cuba:

Off Playa Baracoa, Havana Province; station 3,303; 260 fathoms; 1 young female.

South coast of Cuba:

Bahia de Cochinos, Santa Clara Province; station 3,330; 230-265 fathoms; 1 young female.

Remarks. – These records extend the range of this species to the West Indies, the previous southern limit in American waters being in the Straits of Florida off Key West.

Portunus (Portunus) sayi (Gibbes)

Portunus (*Portunus*) *sayi* Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 37, text-fig. 6, pl. 14, 1930.

One male specimen of this common Sargassum form was taken in Sargassum at the surafce, north of Puerto Tanamo, Oriente Province, Cuba, station 2,973.

Portunus (Portunus) ventralis (A. Milne Edwards)

Portunus (*Portunus*) *ventralis* Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 43, pl. 13, figs. 1, 2, 1930.

One young male of this species was taken in the Old Bahama Channel off Cayo Coco, Camaguey Province, Cuba; station 3,403. The depth at this station was 210 fathoms, but it is very probable that this specimen was taken at the surface when the trawl was drawn in.

Portunus (Achelous) spinimanus Latreille

Portunus (*Achelous*) *spinimanus* Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 62, pls. 26, 27, 28, 1930.

Two males were taken in a crab pot set in four fathoms at Bahia Siguanea, Isla de Pinos, Cuba, February 15, 1938.

Portunus (Achelous) ordwayi (Stimpson)

Portunus (*Achelous*) *ordwayi* Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 71, pl. 33, 1930.

Occurrence.

South coast of Cuba:

Inside Cabo Cruz, Oriente Province; stations 3,347-3,350; 11½-13 fathoms; 1 male, 1 female.

Portunus (Achelous) sebae (H. Milne Edwards)

Portunus (*Achelous*) *sebae* Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 79, pls. 34, 35, 1930.

One female was taken in a trap set off the Naval Station dock at Bahia de Guantanamo, Oriente Province, Cuba, April 13, 1939.

Portunus (Achelous) spinicarpus (Stimpson)

Portunus (*Achelous*) *spinicarpus* Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 92, pl. 45, 1930.

Occurrence.

North coast of Cuba:

Off Caibarien, Santa Clara Province; station 3,420; 190 fathoms; 1 male, 2 females; station 3,421; 235 fathoms; 1 male, 2 females.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,982C; 195-225 fathoms; 1 female; station 2,982D; 150-180 fathoms; 2 males, 1 female; station 3,409; 200 fathoms; 3 males; station 3,412; 235 fathoms; 2 females; station 3,413; 215 fathoms; 1 female; station 3,414; 230 fathoms; 1 male; station 3,415; 210 fathoms; 1 male, 1 female; station 3,416; 200 fathoms; 1 female; station 3,419; 180 fathoms; 1 male.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,391; 220 fathoms; 1 chela; station 3,392; 225 fathoms; 1 male; station 3,393; 220 fathoms; 1 male; station 3,401; 235 fathoms; 1 female; station 3,404; 215 fathoms; 2 males; station 3,405; 235 fathoms; 2 females.

Old Bahama Channel off western end of Cayo Romano, Camaguey Province; station 3,390; 180 fathoms; 1 male.

Off Puerto Tanamo, Oriente Province; station 3,371; 295 fathoms; 1 female.

South coast of Cuba:

Bahia de Cochinos, Santa Clara Province; station 2,962C; 210 fathoms; 1 female; station 3,320; 185 fathoms; 1 ovigerous female.

Remarks. – All of these specimens differ from Miss Rathbun's description and approach *P.* (*A.*) *iridescens* (Rathbun) from the Pacific coast of Mexico in having the posterior angles of the carapace distinctly angular and in several specimens this angle could easily be called spiniform; this is particularly true of the three males from station 3,409. A distinctive feature of this species is the flattened, iridescent surface on each segment of the palps of the outer

maxillipeds. Several of the present series are quite large; the largest male has the carapace 33.0 mm. long and 67.0 mm. broad, including the lateral spines, and the largest female yields corresponding measurements of 34.0 mm. and 63.8 mm. respectively.

Callinectes sapidus sapidus Rathbun

Callinectes sapidus Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 99, text-figs. 15a, 16c, 17c, 18a, 19, pl. 47, 1930.

One immature female was taken from a creek at Cienfuegos. Santa Clara Province, Cuba, February 19, 1938.

Callinectes ornatus Ordway

Callinectes ornatus Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 114, text-figs. 15b, 16a, 17a, 18b, pl. 50, 1930.

Three males, one female and five young were taken along the shore at Bahia Siguanea, Isla de Pinos, Cuba, February 14 and 15, 1938.

Callinectes danae Smith

Callinectes danae Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 118, text-figs. 15d, 16b, 17b, 18d, pl. 51, 1930.

Four males and three females were taken in a fish trap set off the dock in four fathoms at Cienfuegos, Santa Clara Province, Cuba. March 29 to April 1, 1939.

Callinectes exasperatus (Gerstaecker)

Callinectes exasperatus Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 130, text-figs. 15f, 16f, 17e, 18e, pl. 56, 1930.

One male, one female and one young were taken along the shore at Bahia Siguanea, Isla de Pinos, Cuba, February 14, 1938.

Family XANTHIDAE

Carpilius corallinus (Herbst)

Carpilius corallinus Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 240, pls. 97-99, 1930.

Two males and one female were presented to the expedition by fishermen at Bahia de Matanzas, Matanzas Province, Cuba. The female was acquired March 19. 1938, and the two males May 7, 1939.

Panopeus herbstii H. Milne Edwards

Panopeus herbstii Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 335, text-figs. 52, 53, pls. 56, 57, 1930.

One male was taken in a seine along the shore at Bahia Siguanea, Isla de Pinos, Cuba, February 14, 1938; fourteen males and three females were taken in a trap set in four fathoms at Cienfuegos, Santa Clara Province, Cuba, from March 29 to April 3, 1939; one male was found in a creek at Cienfuegos, February 19, 1938; and one male was taken in a trap at the Naval Station dock at Bahia de Guantanamo, Oriente Province, Cuba, April 13, 1939.

The specimen from Bahia Siguanea undoubtedly belongs to *forma obesa* and the specimen taken from the creek at Cienfuegos probably also belongs to this *forma*, although the gastric region is less swollen than in the preceding specimen. All of the others are representative of *forma crassa*, although some of the smaller specimens, particularly the females, taken in the trap at Cienfuegos approach *forma obesa*.

Eurytium limosum (Say)

Eurytium limosum Rathbun. M. J., U. S. Nat. Mus. Bull. 152, p. 423, pl. 176, figs. 1, 2, 1930.

Two males were presented by a fisherman at Cienfuegos, Santa Clara Province, Cuba, February 20, 1938.

Micropanope urinator (A. Milne Edwards)

Micropanope urinator Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 451, pl. 182, figs. 3, 4, pl. 183, figs. 1-3, 1930.

Occurrence.

North coast of Cuba:

Off Caibarien. Santa Clara Province; station 3,422; 235 fathoms; 1 male; station 3,430; 235 fathoms; 1 female.

Remarks.—The male in the present collection is considerably larger than previously recorded specimens, the carapace measuring 12.0 mm. long and 17.2 mm. broad.

The holotype of *M. urinator* is deposited in the Museum of Comparative Zoölogy (Cat. No. 9,159) and not in the Paris Museum as noted by Miss Rathbun.

Micropanope levimanus, sp. nov.
(Figs. 13, 14)

Holotype. – Female, M. C. Z. No. 10,903; inside Cabo Cruz, Oriente Province, Cuba; lat. 20° 03′ N., long. 77° 55′ W.; 11-13 fathoms; April 9, 1939; stations 3,347-3,350.

Paratypes. – Two males, one ovigerous female from the same locality.

Description. – Carapace very broad and convex antero-posteriorly, minutely granulate anteriorly and laterally, smooth on the central portion of the posterior half; areolations well marked. Front made up of two convex lobes separated by a median incision and not produced as lobes at the lateral angles; there is a transverse row of setae behind the frontal margin. Five antero-lateral teeth; post-ocular tooth small, second tooth a low lobe separated from the first by a shallow sinus, third tooth broad and somewhat rounded, fourth salient and acute, fifth very small and acute; all of the teeth are minutely granulate. Orbital margin minutely granulate with two closed fissures in the dorsal margin; outer sinus broad and shallow; an obtuse tooth at inner angle of lower margin. Subhepatic region finely granular with a low elevation but no distinct tubercle.

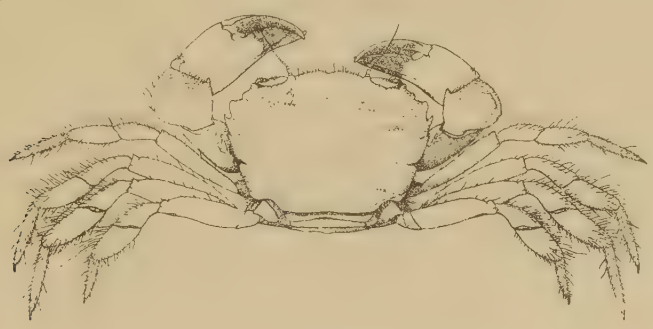


Fig. 13
Micropanope levimanus. Holotype × 3.

Chelipeds unequal. Carpus with sharp granules on the distal portion, a deep distal groove and a blunt spine at inner angle. Hands inflated and smooth except for a few minute granules at carpal articulation. Fingers channeled, irregularly armed with teeth and crossing at the tips when closed; there is a blunt basal tooth on the movable finger of the larger chela; movable finger about one-third again as long as upper margin of palm; dark color of fixed finger not extending as far as palm. Walking legs smooth, sparsely setose on upper margin of merus, densely hairy on margins of three distal segments.

Measurements. – Female holotype, length of carapace 6.2 mm., breadth of carapace 9.3 mm., fronto-orbital width 6.8 mm., width of front 3.1 mm. The three paratypes are all somewhat smaller. the larger male having the carapace 5.2 mm. long and the ovigerous female 5.8 mm. long.

Remarks. – This species is extremely near *M. lata* (Faxon, 1893) from the Bay of Panama, with the type of which it has been compared. The only important differences between the two species are the proportionately shorter fingers of the chelae and the presence of a basal tooth on the movable finger of the larger chela in *M.*

FIG. 14
Micropanope levimanus
A. Outer face of right chela. × 6.3.
B. Outer face of left chela. × 6.3.
C. Abdomen of male paratype. × 6.3.

levimanus. M. xanthiformis, the most closely related Atlantic form, differs in having the carapace and hands coarsely granular and in having the outer angles of the front distinctly produced.

There is a female specimen in poor condition in the Museum of Comparative Zoölogy collected by Dr. H. L. Clark at Port Antonio, Jamaica, in March, 1909, which apparently belongs to *M. levimanus.*

TETRAXANTHUS BIDENTATUS (A. Milne Edwards)

Xanthodes bidentatus A. Milne Edwards, Crust. Rég. Mexico, p. 353, pl. 53, figs. 5-5b, 1880.

Tetraxanthus rugosus Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 459, pl. 185, 1930.

Tetraxanthus bidentatus Chace, F. A., Mem. Soc. Cubana Hist. Nat., vol. 13, no. 1, p. 52, 1939. Not *T. bidentatus* Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 458, pl. 184, 1930

Occurrence.

North coast of Cuba:

Off Playa Baracoa, Havana Province; station 3,302; 230 fathoms; 1 female; station 3,303; 260 fathoms; 1 male, 1 female.

Off Bahia de Matanzas, Matanzas Province; station 3,482; 190 fathoms; 1 female.

Remarks. – Although all four specimens are less than half as large as the male holotype from off Grenada, they agree with that specimen in all other important particulars. There is little doubt that *T. rugosus* Rathbun, 1930, must be synonymized with this species.

Tetraxanthus rathbunae Chace

Tetraxanthus bidentatus Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 458, pl. 184, 1930. Not. *Xanthodes bidentatus* A. Milne Edwards, Crust. Rég. Mexico, p. 353, pl. 53, figs. 5-5b, 1880.

Tetraxanthus rathbunae Chace, F. A., Mem. Soc. Cubana Hist. Nat., vol. 13, no. 1, p. 52, 1939.

Occurrence.

North coast of Cuba:

Off Caibarien, Santa Clara Province; station 3,420; 190 fathoms; 3 males, 1 female; station 3.421; 235 fathoms; 1 male.

Western end of Old Bahama Channel; station 2,983; 235-260 fathoms; 1 male (paratype).

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,982D; 150-180 fathoms; 1 male (holotype); station 2,982E; 150-180 fathoms; 1 male, 1 ovigerous female (paratypes); station 3,409; 200 fathoms; 2 males; station 3,411; 260 fathoms; 1 male; station 3,413; 215 fathoms; 1 female; station 3,414; 230 fathoms; 1 male; station 3,415; 210 fathoms; 2 males; station 3.416; 200 fathoms; 1 ovigerous female; station 3,419; 180 fathoms; 1 male.

Old Bahama Channel off Cayo Coco; Camaguey Province; station 3,391; 220 fathoms; 1 male.

South coast of Cuba:

Bahia de Cochinos, Santa Clara Province; station 3,331; 230-260 fathoms; 1 male; station 3,333; 190-200 fathoms; 1 young female.

Remarks. – As previously stated, examination of the holotype of *Xanthodes bidentatus* A. Milne Edwards has disclosed that Miss Rathbun referred the wrong one of the two known species of *Tetraxanthus* to this species. The type of *T. bidentatus* agrees with Miss Rathbun's description and figure of *T. rugosus* and the latter must, therefore, be synonymized. Since no name was available for the form generally known as *T. bidentatus* it has been called *T. rathbunae.*

Menippe mercenaria (Say)

Menippe mercenaria Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 472, text-fig. 78, pls. 191-193, 1930.

One female was taken in a fish trap set in four fathoms off the dock at Cienfuegos, Santa Clara Province, Cuba, March 30, 1939.

Family CANCRIDAE

Cancer borealis Stimpson

Cancer borealis Rathbun, M. J., U. S. Nat. Mus. Bull. 152, p. 182, text-fig. 30, 1930.

One female was taken by "Atlantis" east of St. Augustine, Florida; 30° 21′ N., 79° 55′ W.; 230-250 fathoms; station 3,779; February 24, 1940.

Family GONEPLACIDAE

Geryon quinquedens Smith

Geryon quinquedens Smith, S. I., Trans. Connecticut Acad. Arts and Sci., vol. 5, p. 35, pl. 9, figs. 1, 1a, 1b, 2, 1879; Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 271 (part - not figured specimen), 1937.

Occurrence.

North coast of Cuba:

Northwest of Cabo San Antonio, Pinar del Rio Province; station 3,313; 550 fathoms; 1 male.

Off Bahia de Cardenas. Matanzas Province; station 2,996; 470-665 fathoms; 1 male.

Off Bahia de Santa Clara, Santa Clara Province; station 2,992A; 555 fathoms; 1 female; station 2,993; 580 fathoms; 1 male; station 3,459; 500 fathoms; 1 male.

Remarks. – These specimens agree very well with specimens of similar size taken off the east coast of the United States, except that the median pair of frontal teeth are slightly more advanced than in most of the more northern specimens. The largest Cuban specimen, a male, has the carapace 123 mm. long to the tips of the frontal teeth, and 144.5 mm. in greatest width. For a comparison of this species with *G. affinis* see remarks under the latter species.

Geryon affinis A. Milne Edwards and Bouvier

Geryon affinis A. Milne Edwards and Bouvier, Res. Camp. Sci. Monaco, vol. 7, p. 41, text-figs. A-D, pl. 1, 1894 (type locality, off the Azores); Doflein, F., Wiss. Ergebn. "Valdivia" Exped., vol. 6, p. 106, pls. 3, 4, 33, 34, pl. 38, figs. 1-6, pl. 41, figs. 3-7, pl. 43, figs. 2, 8, 1904.

Geryon quinquedens Rathbun, M. J., U. S. Nat. Mus. Bull. 166, p. 271 (part), pls. 85, 86, 1937.

Ocurrence. – Two fine male specimens of this species were taken by "Atlantis" in 1940 east of St. Augustine, Florida. One was taken at station 3,781; 30° 58′ N., 79° 34′ W.; 265-290 fathoms; February 24, 1940. The other was found at station 3,783; 30° 03′ N., 78° 37′ W.; 425-430 fathoms; February 25, 1940.

Remarks. – There is little doubt that the specimen figured by Miss Rathbun as *G. quinquedens* is really *G. affinis.* The specimens collected by "Atlantis" agree with the descriptions and figures of Milne Edwards and Bouvier and of Doflein and differ markedly from *G. quinquedens* as shown in the table below; it is noteworthy that Miss Rathbun's figured specimen came from the same general locality as the "Atlantis" specimens. Although all six described species of *Geryon* (not including *G. incertus* Miers which obviously does not belong in the genus) are remarkably similar to one another, there is little difficulty in separating large specimens of *G. affinis* from equally large examples of *G. quinquedens.* In the following table are shown the distinguishing characters of the two species.

G. QUINQUEDENS	G. AFFINIS
Median pair of frontal teeth short, separated by a narrow sinus and produced beyond lateral teeth for their entire length.	Median pair of frontal teeth longer, separated by a broader sinus and extending but little beyond lateral teeth.
Front distinctly wider than orbits.	Front but little wider than orbits.
A sharp subdistal spine on upper margin of merus of cheliped.	At most a blunt tooth on upper margin of merus of cheliped.
A spine on outer margin of carpus of cheliped.	Outer margin of carpus of cheliped unarmed.
Meri of ambulatory legs with a prominent distal spine on upper margin.	Meri of ambulatory legs unarmed.
Length of merus of last leg nearly or quite two-thirds width of carapace.	Length of merus of last leg scarcely more than half width of carapace.
Propodus of last leg five to more than seven times as long as wide.	Propodus of last leg less than four times as long as wide.
Propodus of last leg about one and one-half times as long as dactyl.	Propodus and dactyl of last leg subequal in length.
Dactyls of ambulatory legs very broad and flattened.	Dactyls of ambulatory legs narrow and compressed.

Although there is a good deal of variation, as in all species of the genus, large individuals of these two species can be readily separated by the form of the front, the presence or absence of an outer spine on the carpus of the chelipeds, the presence or absence of a terminal spine on the meri of the ambulatory legs, the much longer ambulatory legs in *G. quinquedens* and, as Milne Edwards and Bouvier have pointed out so well, by the very different form of the dactyls of the ambulatory legs. Smaller specimen of *G. quinquedens* differ from the large ones in so many points that the form of the ambulatory dactyls is the only reliable diagnostic character.

The larger of the two specimens of *G. affinis* at hand has the carapace 125 mm. long to the level of the tips of the frontal teeth and 152 mm. in maximum breadth.

Besides the type locality in the region of the Azores, *G. affinis* is known from the South Atlantic from off the coast of South Africa and from the Indian Ocean off the African and Indian coasts.

Trizocarcinus tacitus, sp. nov.

(Figs. 15, 16)

Goneplax tridentata Boone, L., Bull. Bingham Oceanogr. Coll., vol. 1, art. 2, p. 10, fig. 2, 1927; Bull. Vanderbilt Mar. Mus., vol. 2, p. 194, pl. 66, fig. A, 1930. Not *G. tridentata* (A. Milne Edwards, 1880)

Holotype. – Male, M. C. Z. No. 5.646, collected by the "Blake" at station 274 off Barbados in 209 fathoms, 1878-79.

Description. – Carapace about three-fourths as long as broad; cardiac and posterior branchial regions crossed by a blunt transverse ridge, behind which the surface is nearly flat and in front of which it is convex in both directions. Carapace more or less uneven but only the mesogastric and cardiac regions are demarcated. Surface minutely granulate and bare except for some short hairs on lower part of lateral surfaces. Front bimarginate, the true frontal margin faintly sinuous, the submarginal ridge straight. Front separated by a notch from the subacute inner angle of the orbit. Upper margin

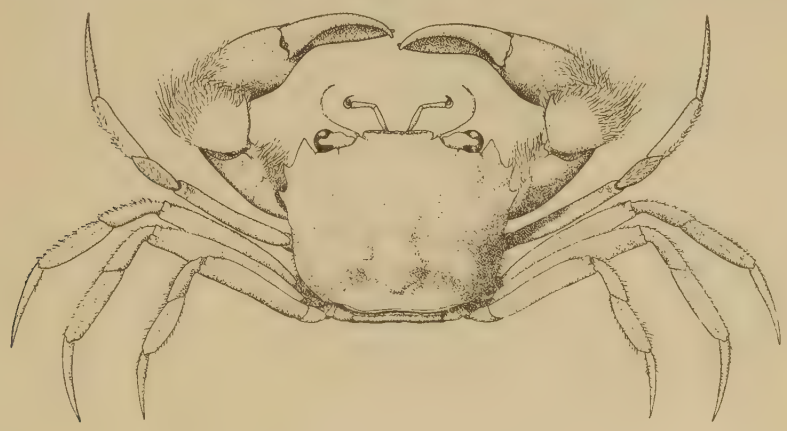


Fig. 15
Trizocarcinus tacitus. Holotype. × 1.

of orbit with two notches and there is a closed fissure below the outer tooth. Antero-lateral margin armed with three somewhat flattened teeth, the second and third smaller and more upturned than the first or extra-orbital tooth. Margins of orbit and antero-lateral teeth not denticulate. Postero-lateral margins slightly convergent. There is a ridge on the pterygostomian region passing obliquely bacwards from the antero-lateral angle of the buccal cavity, but it is not striate and so cannot act as a stridulating organ.

Chelipeds subequal, the right chela vrey slightly larger than the left; merus with a sharp spine on upper margin and a thick mat

of hairs on anterior surface; carpus with a curved tooth on inner margin and a mat of hairs anteriorly; chela with a similar hairy covering on proximal portion only. Ambulatory legs fringed with short hairs, particularly on the carpal and propodal joints.

Male abdomen with all of the joints distinct and the third completely covering the sternum between the last pair of legs.

Measurements. – Male holotype, length of carapace 23.8 mm., maximum width of same 32.2 mm., inter-orbital width 24.9 mm., width of front 9.3 mm.

Remarks. – This specimen was apparently overlooked when the "Blake" material was sent to A. Milne Edwards, and Dr. Faxon had labeled it, "Subf. Carcinoplacinae".

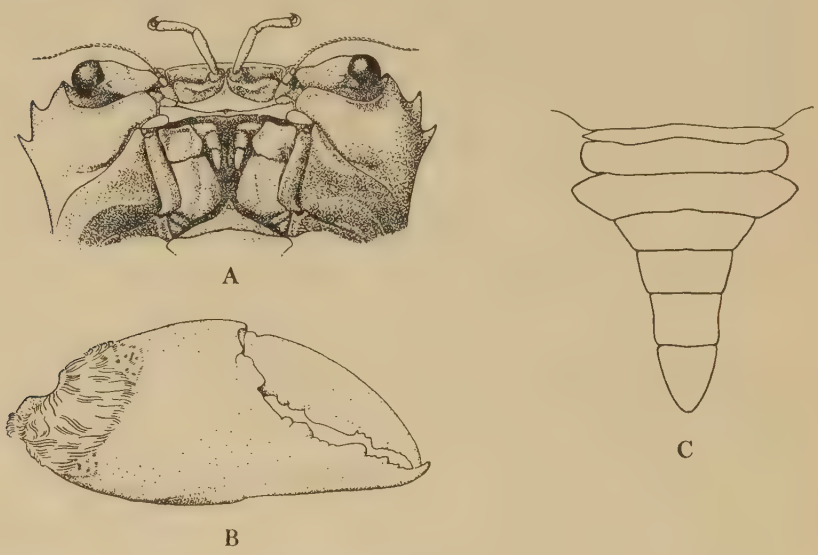


FIG. 16
Trizocarcinus tacitus
A. Bucal area of holotype. × 1.8.
B. Outer face of right chela of holotype. × 1.8.
C. Abdomen of holotype. × 2.4.

There is little doubt that Miss Boone's figure 2 (1927) represents this species, and her description also applies fairly well to the "Blake" specimen. There is some doubt as to the sex of the "Pawnee" specimen as Miss Boone refers to it twice as a female and twice as a male; her figures 3 and 4 certainly appear male-like despite the accompanying legend, but the abdomen does not wholly

agree with that of the "Blake" specimen as may be seen by comparison of the figures. Inquiry of the Bingham Foundation unfortunately discloses that no specimen corresponding to figure 2 can now be found in their collections. The photograph of the specimen in the Vanderbilt Museum also leaves little doubt that it is this species.

T. tacitus differs from *T. dentatus* (Rathbun) from the Gulf of California in the absence of striae on the pterygostomian ridge, the bare and nearly smooth dorsal surface of the carapace, the non-denticulate margins of the orbit and antero-lateral teeth and the absence of a hairy covering on the greater part of the outer surface of the cehelae.

Bathyplax typhla A. Milne Edwars

Bathyplax typhla Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 19, pl. 2, 1918.
Bathyplax typhlus A. Milne Edwards and Bouvier, Mem. Mus. Comp. Zoöl. Harv., vol. 47, no. 4, p. 333, text-fig. 1, pl. 2 ,fig. 9, pl. 5, fig. 7, 1923.

Occurrence:

North coast of Cuba:
Off Bahia de Cardenas, Matanzas Province; station 2995; 370-605 fathoms; 1 male.

Remarks. – Contrary to Bouvier's statement implying that but two specimens of this species were taken by the "Blake", there are three cotypes in the Museum of Comparative Zoölogy, two females taken at station 130 off St. Croix and one male from station 221 off St. Lucia.

Pilumnoplax americana Rathbun

Pilumniplax americana Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 21, text-fig. 5, 1918.

Ocurrence. – One female was taken by "Atlantis" east of St. Augustine, Florida; 30° 27′ N., 79° 52′W.; 250-265 fathoms; February 24, 1940; station 3,780.

Remarks. – In addition to a paratype from off Georgia, there are in the Museum of Comparative Zoölogy two other specimens of this species. One. a male, was taken by the "Blake" off Guadeloupe in 150 fathoms at station 164 in 1878-79; the other, a mutilated female

of large size, was found in the stomach of a specimen of the smooth dogfish, *Mustelus canis* (Mitchell), collected off Havana. Cuba, by Dr. L. Howell Rivero in 1937.

Pilumnoplax nitida, sp. nov.
(Figs. 17, 18)

Holotype. – Male, M. C. Z. No. 10,939; off Caibarien, Santa Clara Province, Cuba; lat. 22° 52′ 30″ N., long. 79° 20′ W.; 240 fathoms; May 1, 1939; station 3,427.

Paratypes.

North coast of Cuba:

Off Caibarien, Santa Clara Province; station 3,427; 240 fathoms; 6 males, 3 females (1 ovigerous); station 3.422; 235 fathoms; 1 male, 1 female; station 3,423; 245 fathoms; 2 males, 4 females (1 ovigerous); station 3,428; 240 fathoms; 2 males, 1 female; station 3,434; 260 fathoms; 1 male.

Western end of Old Bahama Channel; station 2,983; 235-260 fathoms; 3 males; station 2,983A; 235 fathoms; 1 young.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,981C; 195 fathoms; 2 males, 1 female; station 2,981D; 190-230 fathoms; 1 female; station 2,982; 210 fathoms; 4 males; station 2,982A; 210 fathoms; 1 male, 1 female; station 3,411; 260 fathoms; 1 male; station 3,412; 235 fathoms; 1 male; station 3,414; 230 fathoms; 1 male; station 3,416; 200 fathoms; 1 male; station 3.404; 215 fathoms; 1 male.

Description. – Carapace subquadrate, markedly convex in both directions, smooth. polished and punctate except for some microscopic granulation near the antero-lateral margin and totally devoid of hair; except for a very faint H-form furrow at the juncture of the gastric and cardiac regions, there is no indication of regions. Front deflexed, about two-fifths the width of the carapace not including the lateral spines; margin thin and divided into two convex lobes separated by a median notch. Orbital margin finely granulate with two short, closed fissures above and a broad, shallow notch below outer angle; upper margin nearly transverse; outer angle little prominent. Lateral margin armed with three teeth behind the orbital angle; the first broad, obtuse and joined to orbital angle; the second

a sharp spine separated from the first by a U-shaped interval and directed forward with the outer margin subparallel to longitudinal axis of carapace; the third a sharp, curved spine placed some distance behind the second and directed obliquely outward. Ventral portions of carapace finely granular.

Chelipeds unequal and minutely granulate except for the chelae which are granulate only on extreme proximal portions; ischium with a stout, curved spine on anterior margin; merus rounded trigonal with a tubercle at middle of upper margin; carpus with a very faint subdistal depression but no true groove and with a stout spine on proximal half of inner border; larger chela with the fixed finger broad and compressed but with no convexity on lower margin and with an enlarged tooth at base of movable finger; smaller chela

Fig. 17
Pilumnoplax nitida. Holotype. × 3.

with the fixed finger curiously compressed and broadened to form a pronounced swelling in outline of lower margin; on both chelae, the color extends nearly to the base of the movable finger but covers only the tip of the fixed finger.

Ambulatory legs slender, unarmed. with a few scattered fine hairs on meral jointsmore on carpus and propodus and numerous on the margins of the dactyl.

First three segments of male abdomen of subequal width, the third covering the sternum between the coxae of the last pair of

legs; third, fourth and fifth segments coalesced. Surface of abdomen smooth, of sternum finely granulate.

The merus of the outer maxillipeds is slightly produced at the outer angle.

Measurements. – Holotype, length of carapace 9.8 mm., width, not including lateral spines, 11.9 mm., maximum width 13.0 mm., fronto-orbital width 8.1 mm., width of front 5.0 mm. Male paratype, length of carapace 13.2 mm., maximum width 17.2 mm.

Remarks. – There is some variation as regards the granulation of the carapace and the dilation of the lower margin of the propodus of the smaller chela. In females and small males there is a tendency

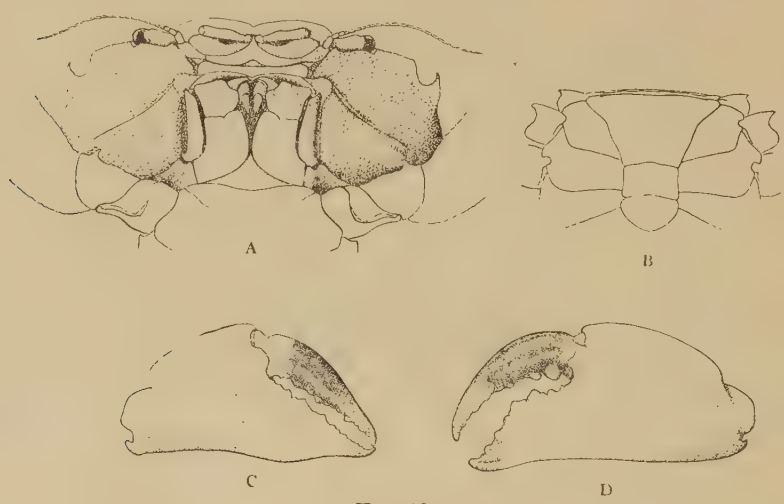


FIG. 18
Pilumnoplax nitida

A. Bucal area of holotype. × 4.
B. Abdomen of holotype. × 4.
C. Outer face of right chela of holotype. × 3.2.
D. Outer face of left chela of holotype. × 3.2.

for the microscopic granulation of the carapace to be more extensive than in the type so that in some specimens it covers nearly all of the dorsal surface; even in these specimens, however, the granules are so low and minute that the surface appears smooth and polished to the naked eye. Likewise, in females and some small males the convexity of the lower border of the propodus of the smaller chela, which is so prominent in larger males, tends to disappear and the

lower margin is perfectly straight or concave; on the other hand, in certain of the larger males this dilation is much more marked than in the type, and in at least one specimen it occurs on the larger as well as the smaller chela.

The generic status of this species is not easily determined. It obviously belongs to the group of the Carcinoplacinae made up of *Carcinoplax, Pilumnoplax* and *Litocheira*. Although it is similar to some of the described species of the first genus, it is far from typical. Due to the very convex carapace and convex frontal lobes it also closely resembles species of the genus *Litocheira* but it lacks the hairy covering usually associated with that genus. Although several workers have attempted to restrict *Pilumnoplax* to species with a flat carapace and straight frontal margin, it seems advisable to include this species here until a revision of these genera is made. Miss Rathbun (1918) has included here the form which she calls *P. elata,* a species which also has the carapace convex and the frontal lobes slightly so. A. Milne Edwards and Bouvier (1923) have pointed out that this species is quite different from the form described as *Eucratoplax elata* by A. Milne Edwards, and examination of the type specimens of *E. elata* in the Museum of Comparative Zoölogy confirms their contention.

Goneplax rosaea (A. Milne Edwards)

Goneplax rosaea Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 27, 1918.
Frevillea rosaea A. Milne Edwards and Bouvier, Mem. Mus. Comp. Zoöl. Harv., vol. 47, no. 4, p. 337, pl. 6, fig. 1, 1923.

Occurrence.

North coast of Cuba:

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,981C; 195 fathoms; 1 male; station 2,981D; 190-230 fathoms; 1 female; station 2,982; 210 fathoms; 2 males, 2 females; station 3,407; 200 fathoms; 1 male; station 3,411; 260 fathoms; 1 female.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,401; 235 fathoms; 1 young.

Remarks. – This is apparently the first record for this species since that of the types from off St. Vincent. The Cuban specimens, although most of them are larger, compare very closely with the

holotype female which is deposited in the Museum of Comparative Zoölogy. The largest male, from station 3,407, has the carapace 23.1 mm., long and 31.0 mm. broad; the largest female, from station 3,411, yields comparative measurements of 22.3 and 31.5 mm.

Pseudorhombila octodentata Rathbun

Pseudorhombila octodentata Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 43, text-figs. 17, 18, pl. 14, fig. 3, 1918.

Occurrence.

North coast of Cuba:

Old Bahama Channel off Punta Alegre, Camaguey Province; station 3,419; 180 fathoms; 1 female.

Remarks. – Unlike the females examined by Miss Rathbun. this specimen is similar to the description of the male; there are four antero-lateral teeth exclusive of the orbital angle, although the first is very small, and the meri of the ambulatory legs bear some small spines in addition to sharp granules on the upper margin.

Chasmocarcinus obliquus Rathbun

Chasmocarcinus obliquus Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 58, text-fig. 27, pl. 14, figs. 1, 2, 1918.

Hephthopelta superba Boone, L., Bull. Bingham Oceanogr. Coll., vol. 1, art. 2, p. 16, fig. 5, 1927.

Occurrence.

North coast of Cuba:

Off Caibarien, Santa Clara Province; station 3,437; 260 fathoms; 1 female.

Old Bahama Channel off west end of Cayo Romano, Camaguey Province; station 3,388; 255 fathoms; 1 male.

South coast of Cuba:

Bahia de Cochinos, Santa Clara Province; station 3 328; 260-275 fthoms; 3 males, 5 females.

Remarks. – In large specimens of this species, the right chela is slightly larger and more inflated than the left; this is true of females as well as males. The largest male collected by "Atlantis" was taken at station 3,328; the carapace of this specimen is 13.0 mm. long and 15.1 mm. broad posteriorly.

Chasmocarcinus cylindricus Rathbun

Chasmocarcinus cylindricus Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 60, text-figs. 28, 29, 1918.

Occurrence.

North coast of Cuba:

Off Bahia Cardenas, Matanzas Province; station 2,995; 370-605 fathoms; 1 female.

Off Caibarien, Santa Clara Province; station 3,423; 245 fathoms; 1 female.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 3,409; 1 male; station 3,417; 200 fathoms; 1 female.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3 394; 1 male, 2 females; station 3.396; 180 fathoms; 2 females; station 3,401; 235 fathoms; 2 females.

Old Bahama Channel off west end of Cayo Romano, Camaguey Province; station 3,390; 180 fathoms; 1 female.

South coast of Cuba:

Bahia de Cochinos. Santa Clara Province; station 3,330; 230-265 fathoms; 1 male; station 3,333; 190-200 fathoms; 1 male; station 3,335; 200 fathoms; 1 male.

Off Bahia de Cienfuegos, Santa Clara Province; station 3 338; 1,075 fathoms; 1 female.

Family CYMOPOLIIDAE

Cymopolia sica A. Milne Edwards

Cymopolia sica Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 208, text-fig. 127, pl. 40, figs. 3, 4, 1918.

Occurrence.

North coast of Cuba:

Off Bahia de Matanzas, Matanzas Province; station 3,482; 190 fathoms; 1 male.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,400; 180 fathoms; 1 female.

Remarks. – The holotype of this species, designated by A. Milne Edwards and Bouvier (1902), is deposited in the Museum of Comparative Zoölogy (Cat. No. 6,503).

Cymopolia depressa (Rathbun)

Cymopolia depressa Rathbun, M J., U. S. Nat. Mus. Bull. 97, p. 212, text-fig. 128, 1918.

Occurrence.

North coast of Cuba:

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,982D; 150-180 fathoms; 1 ovigerous female.

Remarks. – The present specimen is larger than those previously known, the carapace measuring 10.0 mm. in length and 13.0 mm. in width.

Cymopolia cursor A. Milne Edwards

Cymopolia cursor Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 215, text-figs. 130, 131, pl. 52, figs. 1, 2, 1918.

Occurrence.

North coast of Cuba:

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,982; 210 fathoms; 1 ovigerous female; station 2,982C; 195-225 fathoms; 1 ovigerous female.

Off Puerto Tanamo, Oriente Province; station 3 375; 230 fathoms; 1 ovigerous female.

South coast of Cuba:

Bahia de Cochinos, Santa Clara Province; station 2 960; 270 fathoms; 2 ovigerous females; station 2,961D; 195-235 fathoms; 1 ovigerous female; station 2,962C; 210 fathoms; 2 females (1 ovigerous).

Cymopolia gracilis Smith

Cymopolia gracilis Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 218, text-fig. 132, pl. 50, pl. 51, fig. 1, 1918.

Occurrence.

North coast of Cuba:

Off Bahia de Matanzas, Matanzas Province; station 3,468; 375 fathoms; 1 female.

Off Bahia Cardenas, Matanzas Province; station 3,476; 360 fathoms; 1 male.

Cymopolia floridana Rathbun?

Cymopolia floridana Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 220, pl. 41, figs. 3, 4, 1918.

Occurrence.

North coast of Cuba:

Old Bahama Channel off Punta Alegre, Camaguey Province; station 3.410; 260 fathoms; 1 male.

Remarks. – This specimen is imperfect, lacking most of the legs including the second pair of ambulatories. It is obviously closely related to *C. cursor* but is at once separated from that species by the larger eyes which completely hide the outer suborbital tooth from dorsal view and the more prominent and isolated tubercles of the carapace. Since apparently but a single female specimen of *C. floridana* is known, the range of variation of the species is unknown. The "Atlantis" specimen agrees with Miss Rathbun's description in all but a few particulars which may be sexual characters or which may fall within the normal limits of variation of the species. In the present specimen the outer superior orbital tooth is narrower rather than broader than the inner one, the inner suborbital tooth is a long, slender spine reaching nearly to the end of the pterygostomian lobe but hidden by it in ventral view, however, and the first segment of the antennal peduncle is armed distally with an acute ventral tooth, but this tooth could hardly be called a slender spine and it does not reach nearly as far forward as the frontal teeth. In all other particulars Miss Rathbun's description could apply reasonably well to this specimen. It is slightly larger than the type female, the carapace measuring 6.0 mm. in length and 7.8 mm. in width.

Cymopolia gracilipes A. Milne Edwards

Cymopolia gracilipes Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 221, text-fig. 133, pl. 52, figs. 3, 4, 1918.

Occurrence:

North coast of Cuba:

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,396; 180 fathoms; 2 females (1 ovigerous).

Remarks. – The larger of the two specimens has the carapace 6.3 mm. long and 9.8 mm. broad.

Family GRAPSIDAE

Goniopsis cruentata (Latreille)

Goniopsis cruentata Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 237, text-fig. 136, pl. 57, 1918; Bull. Amer. Mus. Nat. Hist., vol. 43, art. 8, p. 443, pl. 39, 1921.
Goniopsis cruentata Boone, L., Bull. Bingham Oceanogr. Coll., vol. 1, art. 2, p. 20, 1927.

Two specimens, a male and a female, of this familiar mangrove crab were presented to the Expedition by a fisherman at Cienfuegos, Santa Clara Province, Cuba, February 20, 1938.

Euchirograpsus americanus A. Milne Edwards

Euchirograpsus americanus Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 282, text-fig. 144, pl. 74, 1918.
Euchirograpsus americanus A. Milne Edwards and Bouvier, Mem. Mus. Comp. Zoöl. Harv., vol. 47, no. 4, p. 351, pl. 9, figs. 5-7, 1923.

Occurrence:

North coast of Cuba:

Off Playa Baracoa, Havana Province; station 3,302; 230 fathoms; 1 male.

Off Caibarien, Santa Clara Province; station 3,422; 235 fathoms; 1 female.

South coast of Cuba:

Bahia de Cochinos, Santa Clara Province; station 2,963C; 205 fathoms; 1 female.

Family GECARCINIDAE

Cardisoma guanhumi Latreille

Cardisoma guanhumi Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 341, pls. 106, 107, 1918.

A large male of this species was taken on the shore at the head of Bahia de Cochinos, Santa Clara Province, Cuba, in 1939. The measurements given by Miss Rathbun are obviously not maximum for this species; the present specimen has the carapace 97 mm. long and 120 mm. broad.

Gecarcinus ruricola (Linnaeus)

Gecarcinus ruricola Rathbun, M. J., U. S. Nat. Mus. Bull. 97, p. 352, text-fig. 160, pls. 117, 118, 1918.

Four specimens of this species, two males and two females, were taken on the eastern shore of Bahia de Cochinos, Santa Clara Province, Cuba, April 4, 1939, and two males were found on a rocky cliff at the Naval Station at Bahia de Guantanamo, Oriente Province, Cuba, March 3, 1938. The specimens from Bahia de Cochinos are of medium size and all are dark-colored, agreeing very closely with the color notes given by Miss Rathbun even after being in preservative and dried. The specimens from Bahia de Guantanamo, however, are much larger and of a uniform light tan color which may or may not have faded in preservative. The larger of these specimens has the carapace 65.5 mm. long and 94. mm. broad.

Family PARTHENOPIDAE

Parthenope (Platylambrus) pourtalesii (Stimpson)

Parthenope (Platylambrus) pourtalesii Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 521, pls. 182, 183, 276, 1925.

Occurrence:

North coast of Cuba:

Off Bahia de Matanzas, Matanzas Province; station 3,482; 190 fathoms; 1 female.

Solenolambrus typicus Stimpson

Solenolambrus typicus Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 537, pls. 192, 193, 279, figs. 1-4, 1925.

Occurrence:

North coast of Cuba:

Off Caibarien, Santa Clara Province; station 3,420; 190 fathoms; 4 males; station 3,421; 235 fathoms; 1 male, 1 ovigerous female; station 3,422; 235 fathoms; 2 males; station 3,423; 245 fathoms; 1 male, 1 ovigerous female; station 3,428; 240 fathoms; 1 young female.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,982A; 210 fathoms; 1 male; station 2,982D; 150-180 fathoms; 4 males, 3 ovigerous females;

station 2,982E; 150-180 fathoms; 2 males; station 3,407; 200 fathoms; 1 female; station 3,409; 200 fathoms; 3 males; station 3,411; 260 fathoms; 2 males; station 3,413; 215 fathoms; 1 female; station 3,414; 230 fathoms; 3 females (2 ovigerous); station 3,415; 210 fathoms; 3 males, 3 females (2 ovigerous); station 3,416; 200 fathoms; 1 ovigerous female; station 3,417; 200 fathoms; 2 males.

Old Bahama Channel off Cayo Coco. Camaguey Province; station 3,391; 220 fathoms; 1 male, 2 females (1 ovigerous); station 3,392; 225 fathoms; 4 males, 1 ovigerous female, 1 young; station 3,393; 220 fathoms; 1 male, 1 ovigerous female; station 3,394; 200 fathoms; 2 males, 3 ovigerous females; station 3 397; 180 fathoms; 1 ovigerous female; station 3,401; 235 fathoms; 5 males, 4 females (2 ovigerous); station 3,402; 230 fathoms; 1 male; station 3 404; 210 fathoms; 1 female.

Solenolambrus tenellus Stimpson

Solenolambrus tenellus Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 541, pl. 194, figs. 3, 4, pl. 279, figs. 5-9, 1925.

Occurrence:

North coast of Cuba:

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,394; 200 fathoms; 2 ovigerous females; station 3,396; 180 fathoms; 7 males; station 3.397; 180 fathoms; 7 males, 5 females (3 ovigerous); station 3,398; 180 fathoms; 1 male, 3 females (2 ovigerous); station 3,399; 180 fathoms; 2 females (1 ovigerous); station 3,400; 180 fathoms; 1 male.

Old Bahama Channel off west end of Cayo Romano, Camaguey Province; station 3,390; 180 fathoms; 1 male, 2 females (1 ovigerous).

Remarks. – Six of these specimens, two males and four females, have rhizocephalan parasites attached beneath the abdomen; all but one of the females without eggs is thus parasitized. Curiously, none of the many specimens of *S. typicus* from approximately the same locality were attacked by this parasite. However, there is a male

specimen of the latter species in the Museum of Comparative Zoölogy taken by the "Blake" off St. Vincent which is parasitized, so the species is not entirely immune from such attacks.

Family MAJIDAE

Stenorynchus seticornis (Herbst)

Stenorynchus seticornis Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 13, text-fig. 3, pls. 2, 3, 1925.

One large female was collected by Mr. William C. Schroeder at Plaza de Puerto Rico, Banes, Oriente Province, Cuba, in 1939, and two males were taken in a trap set off the Naval Station dock at Bahia de Guantanamo, Oriente Province, Cuba, April 13, 1939.

Anomalothir furcillatus (Stimpson)

Anomalothir furcillatus Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 24, text-fig. 6, pl. 8, fig. 2, pl. 9, fig. 2, pl. 206, 1925.

Occurrence:

North coast of Cuba:

Off Playa Baracoa, Havana Province; station 3,303; 260 fathoms; 2 ovigerous females.

Off Bahia de Matanzas, Matanzas Province; station 3,465; 175 fathoms; 1 male, 2 ovigerous females; station 3,468; 375 fathoms; 1 male.

Off Caibarien, Santa Clara Province; station 3,428; 240 fathoms; 1 male.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,982; 210 fathoms; 1 ovigerous female; station 3,412; 235 fathoms; 1 ovigerous female.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,397; 180 fathoms; 1 male; station 3,405; 235 fathoms; 1 soft-shelled female.

Remarks.—There is considerable variation in this species as regards the armature of the lower margin of the merus of the third ambulatory leg. With but one exception, there are but two spines on this segment in the "Atlantis" specimens and in one case these are reduced to sharp granules; the exception is the softshelled female from station 3,405 which has three spines. Two spines is also the

prevalent number among the "Blake" specimens in the Museum of Comparative Zoölogy, although the number varies from one to four. The proximal spine on the carpus of the chelipeds is also frequently missing so that this segment is often armed with but two spines.

ANOMALOTHIR FRONTALIS (A. Milne Edwards)

Anomalothir frontalis Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 25, pl. 8, fig. 1, pl. 9, fig. 1, pl. 207, 1925.

Occurrence:

North coast of Cuba:

Off Bahia de Matanzas, Matanzas Province; station 3,482; 190 fathoms; 1 male, 2 females (1 ovigerous).

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,396; 180 fathoms; 1 male; station 3,397; 180 fathoms; 1 male; station 3,400; 180 fathoms; 1 male; station 3,402; 230 fathoms; 1 male.

Old Bahama Channel off west end of Cayo Romano, Camaguey Province; station 3,390; 180 fathoms; 1 ovigerous female.

PODOCHELA RIISEI Stimpson

Podochela riisei Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 33, pl. 11, figs. 1, 2, pl. 208, fig. 2, 1925.

Occurrence:

South coast of Cuba:

Bahia de Siguanea, Isla de Pinos; 1 male taken in a seine along the shore, February 14 ,1938.

Inside Cabo Cruz, Oriente Province; station 3,347-3,350; 11½ - 13 fathoms; 1 female.

PODOCHELA CURVIROSTRIS (A. Milne Edwards)

Podochela curvirostris Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 50, pls. 19 and 210, 1925.

Occurrence:

North coast of Cuba:

Off Bahia de Matanzas, Matanzas Province; 3.465; 175 fathoms; 1 male, 1 female; station 3,479; 210 fathoms; 1 male; station 3,482; 190 fathoms; 1 male, 1 female.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,397; 180 fathoms; 1 large male.

Euprognatha rastellifera acuta A. Milne Edwards

Euprognatha rastellifera acuta Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 96, pl. 34, figs. 1, 2, 1925.

Occurrence:

North coast of Cuba:

Off Bahia de Matanzas, Matanzas Province; station 2,999; 145-230 fathoms; 1 female.

Old Bahama Channel of Cayo Coco, Camaguey Province; station 3,405; 235 fathoms; 1 ovigerous female.

Old Bahama Channel off west end of Cayo Romano, Camaguey Province; station 3,386; 220 fathoms; 1 ovigerous female.

Remarks.—In the specimen from station 2,999 the dorsal spines of the carapace, although fully as long as in the average specimen of *E. rastellifera acuta,* are slightly capitate as in *E. rastellifera rastellifera.*

Pyromaia cuspidata Stimpson

Pyromaia cuspidata Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 129, text-fig. 49, pl. 41, 1925.

Occurrence:

North coast of Cuba:

Off Bahia de Matanzas, Matanzas Province; station 3,466; 200 fathoms; 1 female.

Off Caibarien, Santa Clara Province; station 3,420; 190 fathoms; 1 ovigerous female; station 3,422; 235 fathoms; 2 females; station 3,423; 245 fathoms; 1 female; station 3,425; 250 fathoms; 1 male; station 3,428; 240 fathoms; 1 male, 3 females.

Western end of Old Bahama Channel; station 2,984; 240-250 fathoms; 1 female.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,981C; 195 fathoms; 2 females; station 2,982A; 210 fathoms; 1 female; station 2,982C; 195-225 fathoms; 3 females; station 2,982D; 150-180 fathoms;

2 males, 4 females; station 2,982E; 150-180 fathoms; 3 males, 4 females; station 3,406; 200 fathoms; 2 males; station 3,407; 200 fathoms; 2 males, 2 females; station 3,408; 200 fathoms; 1 male, 1 female; station 3,409; 200 fathoms; 6 males, 3 females; station 3,413; 215 fathoms; 2 males, 1 female; station 3,414; 230 fathoms; 2 females; station 3,415; 210 fathoms; 1 female; station 3,416; 200 fathoms; 2 males, 2 females; station 3,417; 200 fathoms; 2 males, 2 females.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,391; 220 fathoms; 2 males, 3 females; station 3,392; 225 fathoms; 5 females; station 3,393; 220 fathoms; 3 males, 5 females; station 3,394; 200 fathoms; 1 male, 3 females; station 3,400; 180 fathoms; 1 male; station 3,403; 210 fathoms; 2 males; station 3,405; 235 fathoms; 1 female.

Old Bahama Channel off western end of Cayo Romano, Camaguey Province; station 3,386; 220 fathoms; 1 male; station 3,387; 245 fathoms; 1 female; station 3,389; 220 fathoms; 1 female.

South coast of Cuba:

Bahia de Cochinos, Santa Clara Province; station 2,960; 270 fathoms; 1 female; station 2,963; 150-170 fathoms; 1 female.

Remarks. – This species seems to drop its legs readily; there are but two or three specimens in the collection which have retained all of the legs and several have lost all of them.

Pyromaia propinqua, sp. nov.

(Figs. 19, 20)

Holotype. – Male, M. C. Z. No. 11,061; Old Bahama Channel off Cayo Coco, Camaguey Province, Cuba; lat. 22° 35′ N., long 78° 20′ W.; 180 fathoms; April 28, 1939; station 3,399.

Paratypes.

North coast of Cuba:

Off Caibarien, Santa Clara Province; station 3,420; 190 fathoms; 1 ovigerous female.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 3,419; 180 fathoms; 1 male.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3 391; 220 fathoms; 1 male; station 3,392; 225 fathoms; 1 ovigerous female; station 3,396; 180 fathoms; 1 female; station 3,397; 180 fathoms; 1 ovigerous female.

Old Bahama Channel off west end of Cayo Romano, Camaguey Province; station 3,390; 180 fathoms; 2 males, 1 ovigerous female.

Description. – Regions of carapace well delimited, tumid and adorned with scattered tubercles of varying sizes, but no true spines. Seven of the tubercles are more elevated and prominent then the rest; three median on the mesogastric, cardiac and intestinal regions and one each on the protogastric and branchial regions. In addition, there are four or five spine-like tubercles on the margin of each

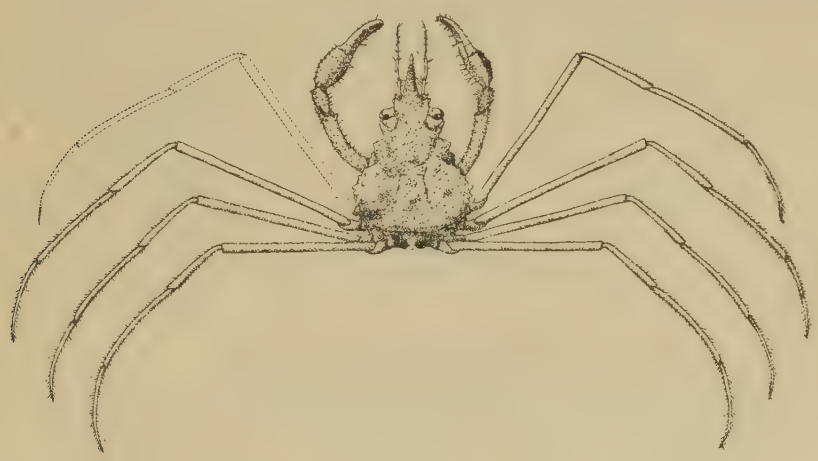


Fig. 19

Pyromaia propincua. Holotype. × 1.5.

branchial region and one on each hepatic region. Rostrum simple, dorsally convex and armed with three rows of sharp tubercles. one median and two marginal. A well developed interantennular spine is present. Supraorbital margin merely angled, not surmounted by a spine. Postorbital tooth but slightly curved around end of cornea and provided with two rows of hairs on the anterior margin.

Basal segment of antenna with a small terminal spine and a blunt tooth directed downward and outward from the outer margin a short distance behind the terminal spine; this is followed by a few marginal

tubercles. Four or five enlarged tubercles on pterygostomian region. Outer maxillipeds as in *P. cuspidata.* Merus of chelipeds armed with numerous short spines, the terminal spine on the upper surface being slightly larger than the others; upper and outer margins of carpus spinulous; chelae subequal with the palm inflated and more or less covered with short spines; fingers curved, evenly dentate on their opposable edges and with a larger tooth near the base of the fixed finger, in back of which there is a slight gap when the fingers are closed. Ambulatory legs covered with a very short pubescence and without spines on any of the segments except for a microscopic spinule occasionally to be found at the end of the merus; the first ambulatory leg is more than two and one-half times as long as the carapace. First abdominal somite armed with a median, backwardly directed spine. Sternum covered with scattered tubercles and abruptly retreating anteriorly.

In females and small males the chelae are subequal and not inflated, and in several specimens the median tubercle on the intestinal region is not enlarged.

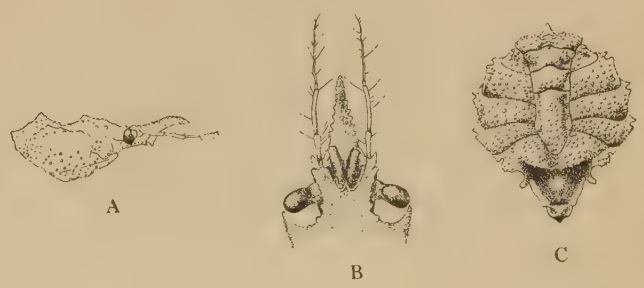


FIG. 20
Pyromaia propincua

A. Lateral view of carapace of holotype. × 1.5.
B. Ventral view of rostrum and orbital reginos of holotype. × 3.
C. Strenum and abdomen of holotype. × 3.

Measurements. – Male holotype, length of carapace 16.2, width 11.9 mm.; ovigerous female, length of carapace 17.5, width 11.5 mm.

Remarks. – This is a smaller species than *P. cuspidata;* in the latter, the abdomen of the female does not become inflated for the reception of the eggs until the carapace attains a length of about 28 mm. *P. propinqua* is otherwise distinguished by its somewhat broader carapace due to the more tumid branchial regions, the absence of sharp spines on the carapace, the shorter and more outwardly directed postorbital tooth, the position of the proximal tooth of the

basal antennal segment on the outer margin rather than toward the median edge and the absence of a strong terminal spine on the merus of any of the ambulatory legs.

This species so nearly bridges the gap between *Pyromaia* and *Anasimus* as far as the form of the postorbital tooth is concerned that the validity of the latter genus is open to question; additional material may well prove it to be synonymous with the former.

Esopus crassus A. Milne Edwards
(Fig. 21)

Esopus crassus Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 192, pl. 222, figs. 10-12, 1925.

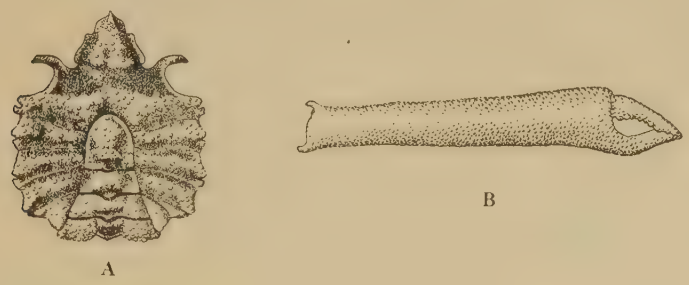


Fig. 21
Esopus crassus
A. Sternum and abdomen of male from station 3,394. × 5.
B. Chela of same specimen. × 5.

Occurrence:

North coast of Cuba:

Old Bahama Channel off Punta Alegre, Camaguey Province; station 3,409; 200 fathoms; 1 male.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,394; 200 fathoms; 1 male; station 3,396; 180 fathoms; 1 male, 1 ovigerous female; station 3.397; 180 fathoms; 3 males. 2 ovigerous females; station 3,398; 180 fathoms; 1 ovigerous female; station 3,399; 180 fathoms; 1 male (with an abdominal parasite); station 3,400; 180 fathoms; 1 male; station 3,401; 235 fathoms; 1 male.

Old Bahama Channel off western end of Cayo Romano, Camaguey Province; station 3,386; 220 fathoms; 1 ovigerous female; station 3.390; 180 fathoms; 2 males, 1 female.

Remarks. – This is apparently the first record of the capture of this species since the unique type was taken by the "Hassler" off the Barbados and it is the first time that the male has been seen. The male differs from the female in having the chelipeds very much longer—usually more than twice as long as the carapace, whereas they are less than the length of the carapace in the female—and in having a large gap between the fingers near the base when they are closed. The male abdomen is composed of six segments, the last two being fused. In both sexes, the ambulatory legs diminish progressively in length from the first to the fourth, and there is a pair of minute, horn-like spines on the margin of the front.

Rochinia crassa (A. Milne Edwards)

Rochinia crassa Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 210, text-figs. 83, 84, pls. 68, 69 and 226, 1925.

Occurrence:

North coast of Cuba:

Off Bahia de Cardenas, Matanzas Province; station 2,996; 470-665 fathoms; 1 young male.

Nicholas Channel, south of Cay Sal Bank; station 2,987E; 315 fathoms; 1 female.

Off Caibarien, Santa Clara Province; station 3,442; 335 fathoms; 1 young female.

In addition to the above specimens, a lot of 4 males, 4 females and 1 young was taken by "Atlantis" east of St. Augustine, Florida, at station 3,779; 30° 21′ N., 79° 55′ W.; 230-250 fathoms; February 24, 1940.

Rochinia hystrix (Stimpson)

Rochinia hystrix Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 214, pls. 70, 71, 1925.

Occurrence:

North coast of Cuba:

Off Playa Baracoa, Havana Province; station 3,303; 260 fathoms; 1 male.

Off Bahia de Matanzas, Matanzas Province; station 2,999; 145-230 fathoms; 1 young.

Nicholas Channel, south of Cay Sal Bank; station 2,987; 280-300 fathoms; 1 male.

Off Caibarien, Santa Clara Province; station 3,431; 245 fathoms:; 1 ovigerous female; station 3,432; 250 fathoms; 1 male, 1 female; station 3,435; 255 fathoms; 1 male; station 3,436; 255 fathoms; 1 female; station 3.437; 260 fathoms; 1 young; station 3,438; 265 fathoms; 1 female.

Western end of Old Bahama Channel; station 2983; 235-260 fathoms; 2 males; station 2 983A; 235 fathoms; 1 ovigerous female.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,980A; 220-260 fathoms; 1 ovigerous female; station 2,980B; 220-225 fathoms; 4 males, 7 females (3 ovigerous); station 2,981; 225 fathoms; 1 male; station 2,982A; 210 fathoms; 2 males, 5 females (2 ovigerous); station 2 982B; 205-230 fathoms; 1 male, 2 females (1 ovigerous); station 2,982C; 195-225 fathoms; 1 female; station 2,982D; 150-180 fathoms; 1 male.

Remarks.—It is perhaps noteworthy that in 1938 25 specimens of this species were taken from seven out of the 15 stations made off Punta Alegre, whereas in 1939 no specimens were found in this general area although 14 stations were made there. To be sure, the species was found in some abundance in the latter year off Caibarien which is but a short distance to the west of Punta Alegre. Whether there is a seasonal migration of this species (stations in 1938 were made on March 10 and 11, those in 1939 on April 29 and 30) or whether its population is so strictly localized that the trawl did not happen to strike a colony in 1939 can hardly be guessed at from this evidence.

Rochinia umbonata (Stimpson)

Rochinia umbonata Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 222, text-fig. 85, pl. 72, pl. 73, fig. 1, 1925.

Occurrence:

North coast of Cuba:

Nicholas Channel off Bahia de Santa Clara, Santa Clara Province; station 3,459; 500 fathoms; 1 female.

In addition, three specimens were taken by "Atlantis" in 1940 east of St. Augustine, Florida. A male was found at station 3,780; 30° 27′ N., 79° 52′ W.; 250-265 fathoms; February 24, 1940. A male and a female were taken at station 3,781; 30° 58′ N., 79° 34′ W.; 265-290 fathoms; February 24, 1940.

Trachymaia cornuta A. Milne Edwards

Trachymaia cornuta Rathbun, M .J., U. S. Nat. Mus. Bull. 129, p. 229, text-fig. 87, pl. 80, pl. 232, figs. 3-5, 1925.

Occurrence:

North coast of Cuba:

Old Bahama Channnel off Punta Alegre, Camaguey Province; station 2,982B; 205-230 fathoms; 1 female; station 2,982D; 150-180 fathoms; 1 female.

Old Bahama Channel off Cayo Coco, Camaguey Province; station 3,391; 220 fathoms; 3 males 2 females (1 ovigerous; station 3,392; 225 fathoms; 1 female; station 3,393; 220 fathoms; 1 male, 1 ovigerous female; station 3,394; 200 fathoms; 1 male, 1 young female; station 3,396; 180 fathoms; 1 ovigerous female; station 3,401; 235 fathoms; 2 males, 2 ovigerous females; station 3,402; 230 fathoms; 1 young male, 1 young female.

Old Bahama Channel off western end of Cayo Romano, Camaguey Province; station 3,386; 220 fathoms; 1 male; station 3,389; 220 fathoms; 1 ovigerous female.

Holoplites armata (A. Milne Edwards)

Holoplites armata Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 307, text-fig. 102, pl. 108, pl. 245, figs. 6-8, 1925.

Occurrence:

North coast of Cuba:

Off Playa Baracoa, Havana Province; station 3,303; 260 fathoms; 2 males, 1 ovigerous female.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 2,980B; 220-225 fathoms; 1 male.

Remarks. – The specimen from station 2.980B is a large and striking specimen measuring 32 mm. in total length and 20 mm. in total width, including the spines; exclusive of the spines, the carapace of this specimen is 20.4 mm. long and 14.2 mm. broad.

TEMNONOTUS GRANULOSUS A. Milne Edwards
(FIG. 22)

Temnonotus granulosus Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 341, pl. 249, fig. 709, 1925.

Temnonotus simplex A. Milne Edwards, Crust. Rég. Mex., p. 84, pl. 17, figs. 3-3c, 1875; Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 342, pl. 249, figs. 10-12, 1925.

Occurrence.

North coast of Cuba:

Off Playa Baracoa, Havana Province; station 3,303; 260 fathoms; 1 male.

Remarks. – Examination of the four specimens of *Temnonotus* in the Museum of Comparative Zoölogy leaves little doubt that *T. simplex* is a synonym of *T. granulosus*. In the smallest specimen examined, the young male holotype of *T. simplex* which has the carapace 11.3 mm. long exclusive of the rostral spines, the cardiac region is simply convex, surmounted by a single tubercle and surrounded, except anteriorly, by a relatively shallow and unmargined trench. The next largest specimen, in which the carapace is 16.1 mm. long, is the male taken off Barbados at "Blake" station 273 and identified by A. Milne Edwards as *T. granulosus* and by Miss Rathbun as *T. simplex;* in this specimen the cardiac region is convex as in the previous one but it is decorated with eight or nine minute tubercles in addition to the median one and the cardiac trench is deeper with a marginal line just forming. Next in point of size, having a carapace length of 21.2 mm.. is the female holotype of *T. granulosus;* here the cardiac region is more flattened and it is surmounted by numerous tubercles; the cardiac trench is deeper and bordered by a distinctly raised margin. Finally, in the large male taken by "Atlantis", in which the carapace measured 23.4 mm., the cardiac region is slightly more flattened than in the latter specimen and the cardiac trench is remarkably deep and broad with a sharply produced margin; unlike the first three examples, the trench here nearly encircles the cardiac region being prevented from so doing

only by a very thin anterior septum. In the holotype of *T. simplex* the basal antennal article is too badly damaged to permit the determination of its armature but, contrary to Miss Rathbun's statement concerning the male collected by the "Blake" the three other specimens have three spines on this segment.

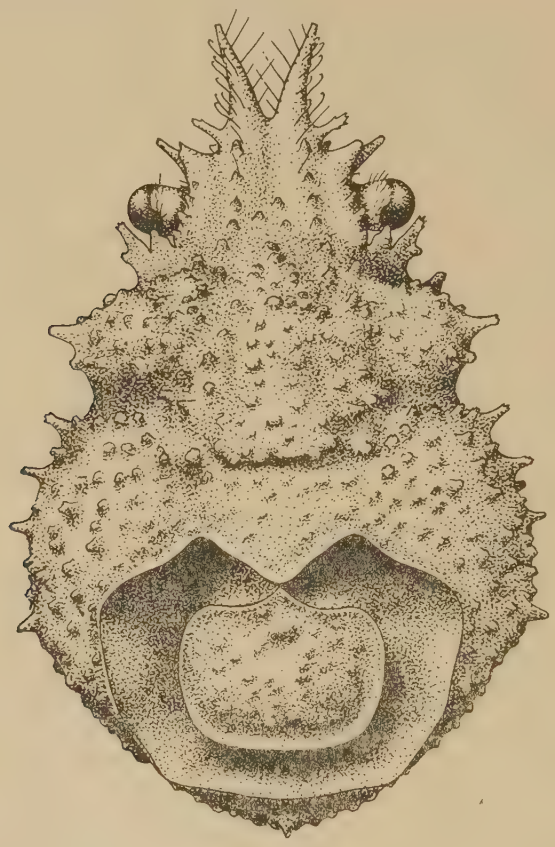


FIG. 22
Temnonotus granulosus A. Milne Edwards
Dorsal view of carapace of male from station 3,303. × 4.

Thus, although all four of these specimens differ somewhat in the form of the cardiac region and its accompanying trench, there is every likelihood, as Miss Rathbun has suggested, that the two described species of the genus are identical; the available material, however, seems to indicate that the individual differences are distinctive less of the sex of the individual than of its age .

Leptopisa setirostris (Stimpson)

Leptopisa setirostris Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 375, text-fig. 120, pl. 134, figs. 1-3, pl. 253, fig. 2, 1925.

Occurrence:

South coast of Cuba:

Inside Cabo Cruz, Oriente Province; station 3,347; 11½-13 fathoms; 1 ovigerous female.

Mithrax (Mithrax) spinosissimus (Lamarck)

Mithrax (Mithrax) spinosissimus Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 383, pl. 135, 1925.

One ovigerous female was bought from a fisherman at Bahia de Matanzas, Matanzas Province, Cuba, March 19, 1938.

Mithrax (Mithraculus) forceps (A. Milne Edwards)

Mithrax (Mithraculus) forceps Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 431, pl. 156, 1925.

Occurrence.

South coast of Cuba:

Inside Cabo Cruz, Oriente Province; station 3,347-3,350; 11½-13 fathoms; 2 males, 3 females (2 ovigerous); station 3,351; 28 fathoms; 1 ovigerous female.

Stenocionops spinosissima (Saussure)

Stenocionops spinosissima Rathbun, M. J., U. S. Nat. Mus. Bull. 129, p. 455, pl. 165, fig. 2, pl. 264, figs. 3 and 4, pl. 265, 1925.

Occurrence:

North coast of Cuba:

Off Playa Baracoa, Havana Province; station 3,303; 260 fathoms; 1 male.

Old Bahama Channel off Punta Alegre, Camaguey Province; station 3.417; 200 fathoms; 1 female.

Remarks. – The male from station 3,303 is a fine large specimen, the measurements of which are as follows: total length of carapace including rostral horns (intestinal spines broken off) 102 mm., width of carapace including spines 85 mm., width of carapace excluding spines 72.5 mm., length of rostral horns 15.7 mm. The female is somewhat smaller, the carapace measuring 86 mm. in total length; this specimen is parasitized by two small rhizocephalans beneath the abdomen.

Contribution No. 274

THE ATLANTIS EXPEDITIONS TO THE WEST INDIES IN 1938 AND 1939, UNDER THE JOINT AUSPICES OF THE UNIVERSITY OF HAVANA AND HARVARD UNIVERSITY

LIST OF STATIONS

Compiled by

FENNER A. CHACE, JR.

Museum of Comparative Zoölogy

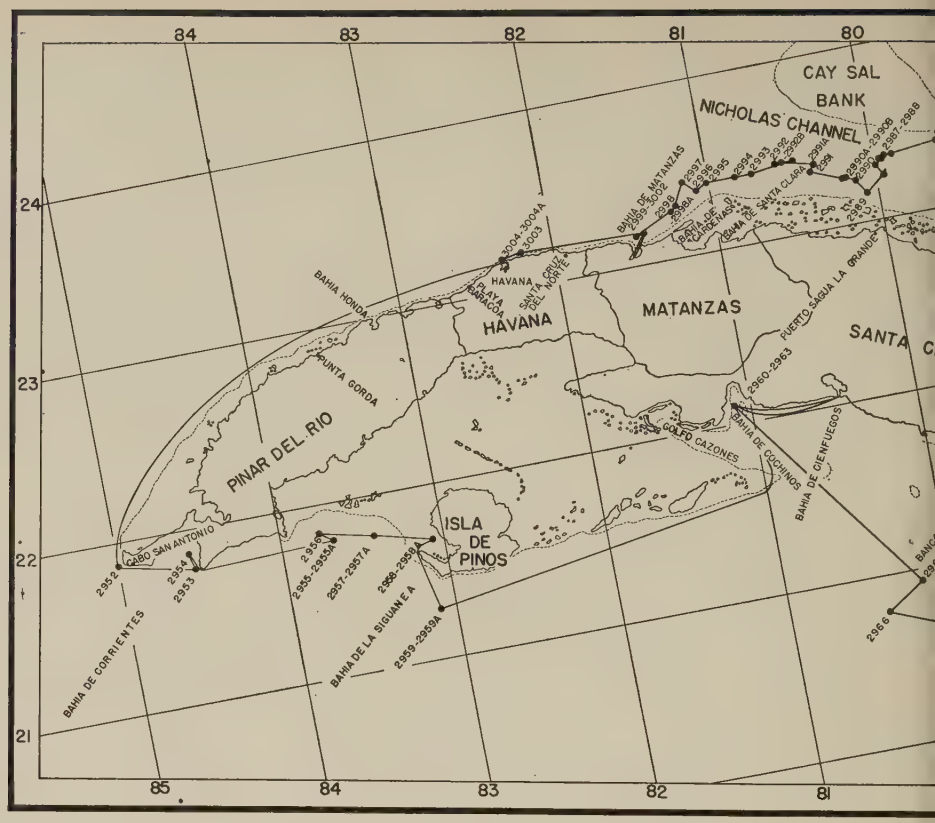
(Contribution No. 274 of the Woods Hole Oceanographic Institution.)

Stations at which no catch was made due to the trawl not being on the bottom or damage to or loss of gear are marked with an asterisk. In the column devoted to the type of gear employed, "Net" refers to a mid-water stramin or twine net of the designated diameter, "Bl. tr." stands for Blake trawl and "Ot. tr." for Otter trawl; the measurements in the two latter cases refer to the width of the trawl. At those stations where mid-water nets were employed, the depth noted in each case is the total depth at that station and not the depth at which the nets fished; usually several nets were used at various depths at each station with the amount of wire out ranging from 50 to 3000 meters. This list contains only those stations at which biological work was done; the missing numbers represent stations at which hydrographic investigations were carried out.

Printed for the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, December, 1940.

Station	Date	Position Latitude N ° ′ ″	Position Longitude W. ° ′ ″	Fathoms	Gear
	1938				
2946	Jan. 29–30	26 12	76 26	2610	Net, 2 m.
2947	" 30	25 11	77 19	730–1000	" " "
2947A	" 30	25 16	77 14	1260	" " "
2947B	" 31	25 16	77 14	1200+	" " "
2948	Feb. 2	25 14	77 22	1200	Net, 9 ft.
2949	" 3	26 06	78 01	625	Bl. tr., 14 ft.
2950	" 3	26 14	78 43	285	" " 10 "
2951	" 3	26 08	79 02	155	" " " "
2952	" 9	21 52	85 00	570	" " " "
2953	" 10	21 47 30	84 32 30	615	Ot. tr., 60 ft.
2954	" 11	21 51	84 34	900	Bl. tr., 10 ft.
*2955	" 13	21 47	83 40	1320	" " " "
*2955A	" 13	21 47	83 40	1275	" " " "
2956	" 13	21 50	83 45	1180–1200	Net, 2 m.
2957	" 13	21 46	83 25	1120	" " "
2957A	" 13	21 46	83 25	1120	" " " & 9 ft.
*2958	" 15	21 41	83 04	4	Ot. tr., 60 ft.
*2958A	" 15	21 41	83 04	4	Ot. tr., 35 ft.
2959	" 15–16	21 17	83 06	2050	Net, 2 m.
2959A	" 16	21 17	83 06	2050	Net, 2 m. & 9 ft.
*2960	" 18	22 07	81 08 30	270	Bl. tr., 14 ft.
2960A	" 18	22 07	81 08 30	270	" " " "
*2960B	" 18	22 07	81 08 30	210– 235	" " " "
*2960C	" 18	22 07	81 08 30	220– 190	Ot. tr., 35 ft.
*2961	" 23	22 07	81 08 30	250– 255	Bl. tr., 10 ft.
2961A	" 23	22 07	81 08 30	205	Ot. tr., 35 ft.
2961B	" 23	22 07	81 08 30	185– 195	" " " "
2961C	" 23	22 07	81 08	190– 210	" " " "
2961D	" 23	22 07	81 08	195– 235	" " " "
2962	" 24	22 07	81 08	200– 210	" " " "
*2962A	" 24	22 07	81 08	215– 225	" " " "
2962B	" 24	22 07	81 08	180 –190	" " " "
2962C	" 24	22 07	81 08	210	" " " "
2962D	" 24	22 07	81 08	175– 210	" " " "
2963	" 25	22 07	81 08	190– 180	" " " "
2963A	" 25	22 07	81 08	155– 190	" " " "
2963B	" 25	22 07	81 08	150– 170	" " " "
2963C	" 25	22 07	81 08	205	" " " "
2963D	" 25	22 07	81 08	220– 275	" " " "
2963E	" 25	22 07	81 08	220– 235	" " " "
*2963F	" 25	22 07	81 08	375– 400	" " " "
2964	" 26	20 56	80 11	2075	" " 60 ft.
2966	" 26	20 47 30	80 24 30	2125	Bl. tr., 14 ft.
2967	Mar. 4	19 47	75 06	1530	" " " "
2967A	" 4	19 46	75 01	1580–1800	" " " "
2967B	" 4	19 43 30	74 57 30	1330–1650	" " " "
2968	" 5	19 40	75 03	1920	" " " "
2969	" 5	19 47	74 59	1075–1145	" " " "
2969A	" 5	19 50	75 00	1010	" " " "
2970	" 5–6	19 51	74 26	1600–1800	" " " "
2971	" 6	20 34	74 24	810	" " " "
2972	" 6–7	20 40	74 25	1200	" " " "
2972A	" 6–7	20 40	74 25	1200	" " " "
*2973	" 7	21 09	75 04 30	1245–1335	" " " "
2973A	" 7	21 13	75 14	1245–1335	" " " "
2974	" 7	21 11	75 32 30	1030	" " " "
2975	" 7	21 13	75 39	1015	" " " "
2976	" 8	21 19	76 05	1450	" " 10 ft.
2977	" 9	21 42	76 59	1175	" " " "
*2978	" 9	21 41 30	77 04	875	" " " "
2979	" 9	21 46	77 13	790	" " " "
2980	" 10	22 47	78 40	250	" " 14 ft.

Station	Date	Position Latitude N. ° ′ ″	Position Longitude W. ° ′ ″	Fathoms	Gear
	1938				
2980A	Mar. 10	22 48	78 41	220– 260	Bl. tr., 14 ft.
2980B	" 10	22 48	78 48	220– 225	" " " "
2981	" 10	22 48	78 48	225	Ot. tr., 60 ft.
2981A	" 10	22 50	78 50	220– 230	" " " "
2981B	" 10	22 47	78 49	195– 225	" " 35 ft.
2981C	" 10	22 47	78 49	195	" " " "
2981D	" 10	22 48	78 51	190– 230	" " " "
2982	" 11	22 48	78 50 30	210	" " " "
2982A	" 11	22 48	78 50	210	" " " "
2982B	" 11	22 47	78 48 30	205– 230	" " " "
2982C	" 11	22 46	78 45	195– 225	" " " "
2982D	" 11	22 44 30	78 41	150– 180	" " " "
2982E	" 11	22 45	78 45	150– 180	" " " "
*2982F	" 11	22 47	78 49	165– 175	" " " "
2983	" 12	23 11	79 08	235– 260	" " " "
2983A	" 12	23 11	79 08	235	" " " "
2984	" 12	23 16	79 10	240– 250	" " " "
2985	" 12	23 23	79 17	250	" " " "
2986	" 13	23 23	79 31	275– 285	" " " "
*2986A	" 13	23 23	79 36	280	" " 52 ft.
2987	" 13	23 22	79 53	280– 300	Bl. tr., 14 ft.
2987A	" 13	23 22	79 56	285– 300	" " " "
2987B	" 13	23 22	79 56	290	" " " "
2987C	" 13	23 21	79 58	300– 315	" " " "
2987D	" 13	23 21	79 57 30	315	" " " "
2987E	" 13	23 19	79 59	315	" " " "
2988	" 14	23 15	79 57	380	" " " "
2989	" 14	23 10	80 04	360	" " " "
2990	" 14	23 15	80 08	390	" " " "
2990A	" 14	23 16 30	80 11	415	" " " "
2990B	" 14	23 16 30	80 12	415	" " " "
2991	" 14	23 21	80 23	475	" " " "
2991A	" 14	23 23	80 21	475	" " " "
2992	" 15	23 26	80 33	555	" " " "
2992A	" 15	23 26	80 35	555	" " " "
2992B	" 15	23 26	80 28	535	" " " "
2993	" 15	23 24	80 44	580	" " " "
2994	" 15	23 24	80 50	565– 585	Ot. tr., 35 ft.
2995	" 16	23 24	81 00 30	370– 605	" " " "
2996	" 16	23 22	81 05	470– 665	" " " "
*2997	" 16	23 26	81 09	655	" " " "
2998	" 16	23 18	81 13	355	Bl. tr., 14 ft.
2998A	" 16	23 16	81 15	365	" " " "
2999	" 17	23 10	81 29	145– 230	" " 10 ft.
2999A	" 17	23 10	81 29	145– 190	" " " "
2999B	" 17	23 10	81 29	115– 135	" " " "
2999C	" 17	23 10	81 29	145– 215	" " " "
3000	" 21	23 10	81 29	170– 255	" " 14 ft.
*3001	" 21	23 11	81 26	355	" " " "
*3002	" 21	23 11	81 26	Surface	Net, 2 m.
3003	" 22	23 12 30	82 12	240– 300	Bl. tr., 10 ft.
3004	" 22	23 11	82 19	185– 205	" " 14 ft.
3004A	" 22	23 11	82 19	140– 195	" " " "
	1939				
3302	Mar. 23	23 04 30	82 34	230	Bl. tr., 10 ft.
3303	" 23	23 05	82 33	260	" " " "
*3304	" 23	23 05	82 34	175	" " " "
3305	" 23	23 05 30	82 35	330	" " 14 ft.
3306	" 23	23 04 30	82 37	330	" " " "
*3308	" 24	23 02	83 20	890	" " 10 ft.
*3309	" 24	23 02 30	83 17	645	" " " "
*3310	" 24	23 02 30	83 17	500	" " " "


CAY SAL BANK
NICHOLAS CHANNEL
BAHIA DE MATANZAS
BAHIA DE CARDENAS
BAHIA DE SANTA CLARA
HAVANA
PLAYA BARACOA
SANTA CRUZ DEL NORTE
BAHIA HONDA
PUNTA GORDA
PINAR DEL RIO
MATANZAS
PUERTO SAGUA LA GRANDE
SANTA C
GOLFO CAZONES
BAHIA DE COCHINOS
BAHIA DE CIENFUEGOS
ISLA DE PINOS
CABO SAN ANTONIO
BAHIA DE CORRIENTES
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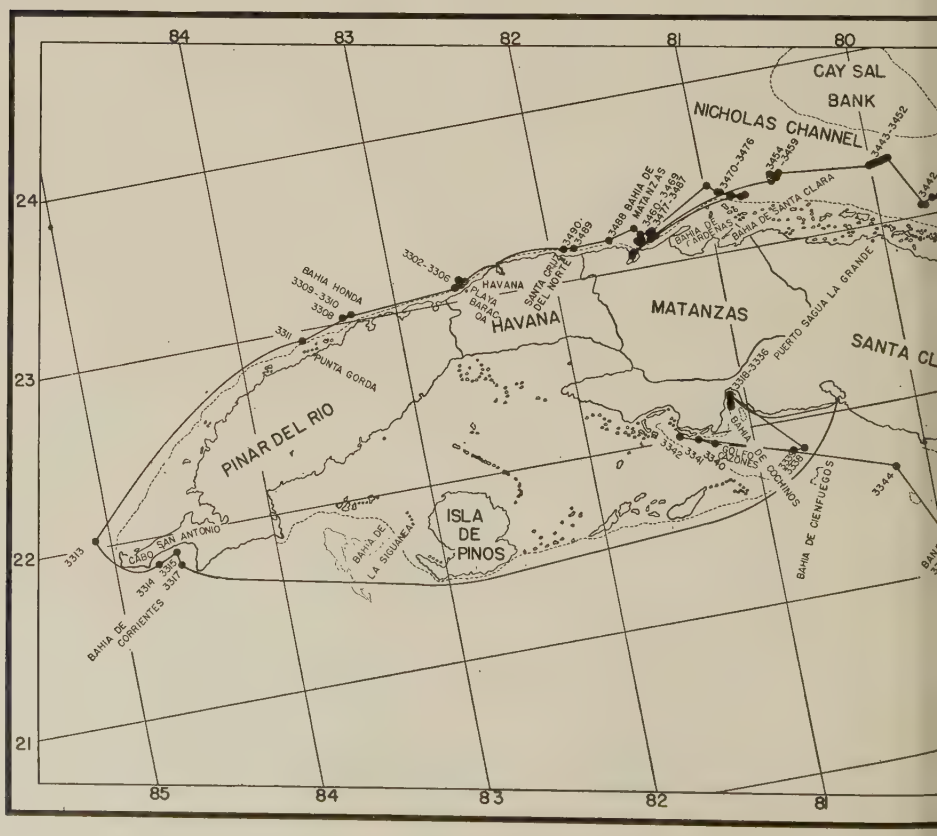
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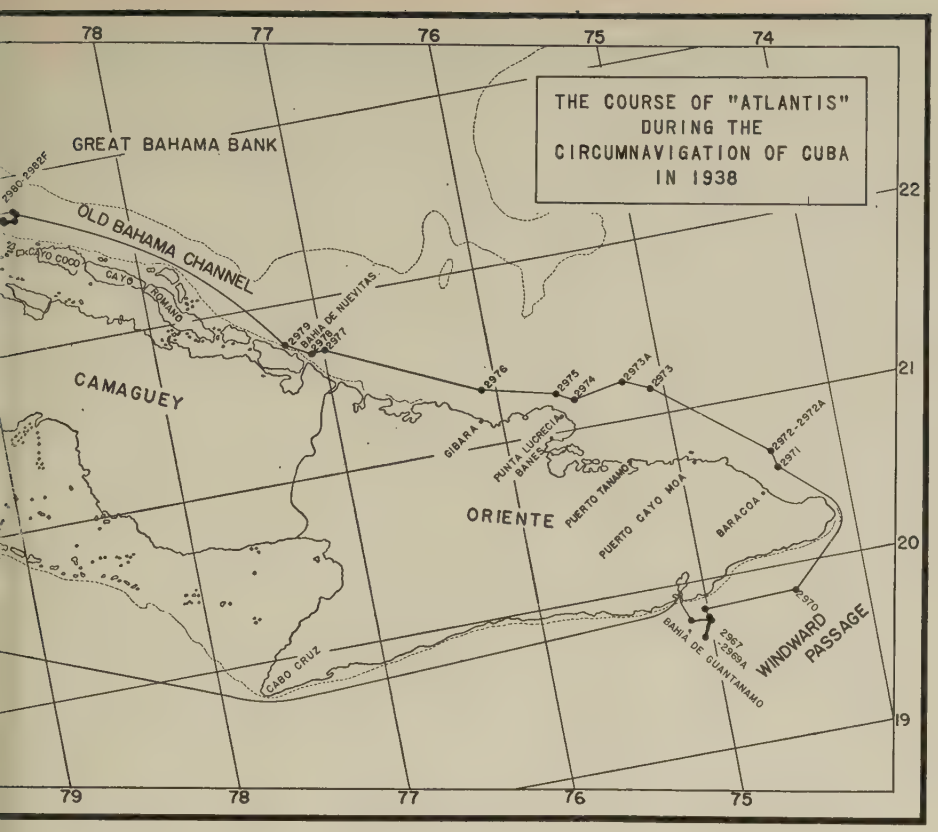
THE COURSE OF "ATLANTIS"
DURING THE
CIRCUMNAVIGATION OF CUBA
IN 1938
GREAT BAHAMA BANK
OLD BAHAMA CHANNEL
CAYO COCO
CAYO ROMANO
BAHIA DE NUEVITAS
CAMAGUEY
GIBARA
PUNTA LUCREECIA
BANES
PUERTO TANAMO
PUERTO CAYO MOA
BARACOA
ORIENTE
BAHIA DE GUANTANAMO
WINDWARD PASSAGE
CABO CRUZ
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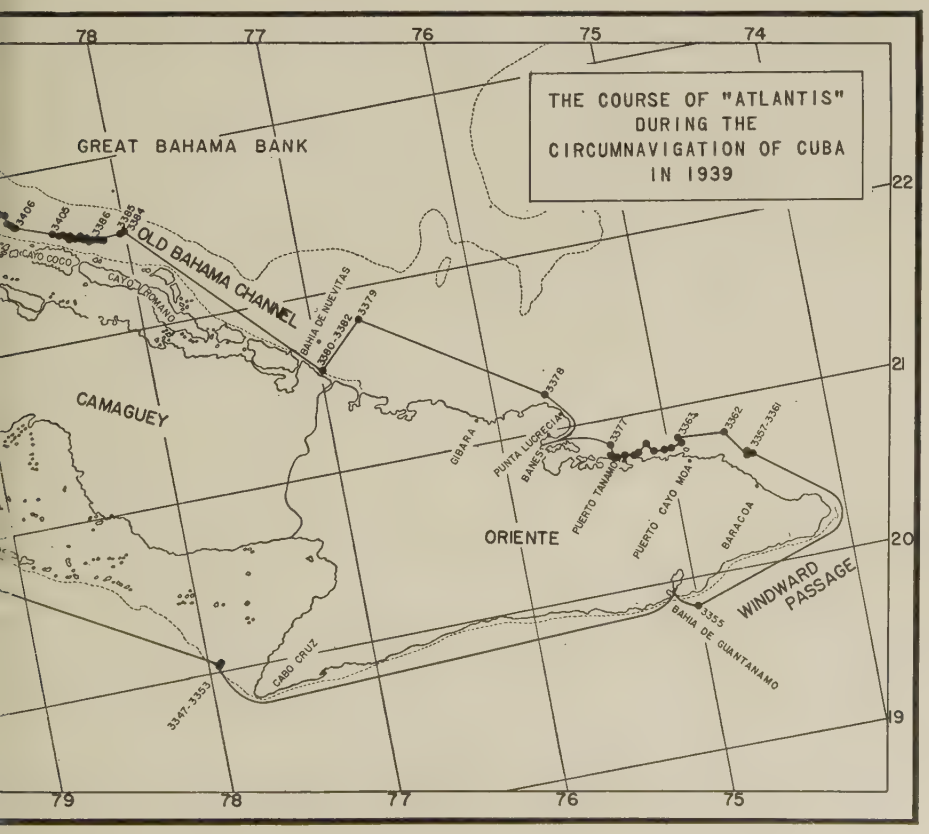
THE COURSE OF "ATLANTIS"
DURING THE
CIRCUMNAVIGATION OF CUBA
IN 1939
GREAT BAHAMA BANK
OLD BAHAMA CHANNEL
CAYO COCO
CAYO ROMANO
BAHIA DE NUEVITAS
CAMAGUEY
GIBARA
PUNTA LUCREECIA
BANES
PUERTO TANAMO
PUERTO CAYO MOA
BARACOA
ORIENTE
BAHIA DE GUANTANAMO
WINDWARD PASSAGE
CABO CRUZ
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Station	Date	Position Latitude N. ° ′ ″	Position Longitude W. ° ′ ″	Fathoms	Gear
	1939				
*3311	Mar. 24	22 57	83 36 30	305	Bl. tr., 10 ft.
3313	" 25	22 02 30	85 06	550	" " " "
3314	" 26	21 50 30	84 44	500	" " " "
3315	" 26	21 54	84 37	350	" " 14 ft.
*3317	" 27	21 49	84 36	1000+	Ot. tr., 35 ft.
*3318	Apr. 4	22 13	81 10	220	" " " "
3319	" 4	22 13	81 10 30	195– 215	" " " "
3320	" 4	22 13	81 11	185	" " " "
*3321	" 4	22 11	81 10 30	250	" " " "
*3322	" 4	22 09 30	81 10	220	Bl. tr., 14 ft.
3323	" 4	22 09	81 09 30	290– 320	" " 10 ft.
3324	" 4	22 08	81 09 30	320	" " " "
3325	" 4	22 09	81 09	300	" " 14 ft.
3326	" 4	22 09	81 09	265	" " " "
3327	" 5	22 10 30	81 09	220– 290	" " " "
3328	" 5	22 08	81 10	260– 275	Ot. tr., 35 ft.
*3329	" 5	22 09	81 10 30	180– 255	" " " "
3330	" 5	22 09 30	81 10 30	230– 265	Bl. tr., 10 ft.
3331	" 5	22 09	81 11	230– 260	" " " "
3332	" 5	22 09 30	81 11	175– 225	" " " "
3333	" 6	22 13	81 11	190– 200	" " " "
3334	" 6	22 13	81 11	185– 195	" " " "
3335	" 6	22 12	81 11	200	" " " "
3336	" 6	22 12	81 11 30	200– 240	" " " "
3338	" 7	21 49 30	80 43	1075	" " " "
*3339	" 7	21 49	80 47	925	" " " "
*3340	" 7	21 56 30	81 14 30	490– 630	" " " "
3341	" 7	21 59	81 20	310– 425	" " " "
*3342	" 7	22 01	81 26	360– 390	" " 14 ft.
3344	" 8	21 38	80 12	1440	" " 10 ft.
3345	" 8	21 08	79 56 30	690– 700	" " " "
3347	" 9	20 03	77 55	13	" " " "
3348	" 9	20 03	77 55	12	" " " "
3349	" 9	20 03	77 55	11½	" " " "
3350	" 9	20 03	77 55	12½	" " " "
3351	" 9	20 02	77 56	28	" " " "
3353	" 9	20 02	77 56	22	" " " "
3355	" 15	19 50	75 00	1070	" " 14 ft.
3357	" 18	20 39	74 30	875	" " " "
3358	" 18	20 40	74 32	975	" " " "
3359	" 18	20 38	74 32	1000	" " " "
*3360	" 18	20 39	74 31	985	" " " "
*3361	" 18	20 38	74 32	960	" " 10 ft.
3362	" 18–19	20 48	74 39	1020	" " " "
3363	" 19	20 49	74 56	830	" " 14 ft.
*3364	" 19	20 47	74 55	710	" " " "
3365	" 19	20 46	74 59	600	" " 10 ft.
3366	" 19	20 46	74 59	625	" " 14 ft.
3367	" 19	20 46	75 02	640	" " " "
*3368	" 19	20 46	75 06	520	" " " "
3369	" 20	20 49	75 08	600	" " " "
3370	" 20	20 47	75 11	450	" " " "
3371	" 20	20 46	75 13	295	" " " "
3372	" 20	20 45	75 17	300	" " 10 ft.
3373	" 20	20 45	75 19	280	" " " "
3374	" 20	20 45	75 19	300	" " 14 ft.
3375	" 20	20 45	75 20	230	Bl. tr., 14 ft.
3376	" 20	20 44 30	75 18	285	" " " "
3377	" 20	20 51	75 21	560	" " " "
*3378	" 24	21 12	75 41	820	" " " "
3379	" 25	21 49	76 43	910	" " 10 ft.
3380	" 25	21 34	76 59	460	" " " "

Station	Date	Position Latitude N. ° ′ ″	Position Longitude W. ° ′ ″	Fathoms	Gear
	1939				
3382	Apr. 25	21 34	77 00	375	Bl. tr., 10 ft.
3384	" 26	22 34	78 00	290	Ot. tr., 35 ft.
3385	" 26	22 33	78 02	290	" " " "
3386	" 26	22 33	78 11 30	220	" " " "
3387	" 26	22 33	78 10	245	" " " "
3388	" 26	22 32 30	78 09	255	" " " "
3389	" 27	22 32	78 08	220	" " " "
3390	" 27	22 33	78 13	180	" " " "
3391	" 27	22 34	78 14	220	" " " "
3392	" 27	22 35	78 16	225	" " " "
3393	" 27	22 36	78 19	220	" " " "
3394	" 27	22 34	78 14	200	" " " "
3396	" 28	22 34	78 15	180	" " " "
3397	" 28	22 34 30	78 16	180	" " " "
3398	" 28	22 35	78 18	180	" " " "
3399	" 28	22 35	78 20	180	" " " "
3400	" 28	22 35	78 19	180	" " " "
3401	" 28	22 36	78 19	235	" " " "
*3402	" 28	22 36	78 21	230	" " " "
3403	" 28	22 36 30	78 22	210	" " " "
3404	" 28	22 37	78 23 30	215	" " " "
3405	" 28	22 38	78 25	235	" " " "
3406	" 29	22 42	78 38	200	" " " "
3407	" 29	22 42	78 39	200	" " " "
3408	" 29	22 43	78 40	200	" " " "
3409	" 29	22 44	78 41	200	" " " "
3410	" 29	22 47	78 41	260	" " " "
3411	" 29	22 47 30	78 43	260	" " " "
3412	" 29	22 49	78 48	235	" " " "
3413	" 29	22 50	78 50	215	" " " "
3414	" 29	22 50 30	78 52	230	" " " "
3415	" 29	22 51 30	78 55 30	210	" " " "
3416	" 30	22 50	78 55	200	" " " "
3417	" 30	22 50	78 56	200	" " " "
3418	" 30	22 49	79 00	195	" " " "
3419	" 30	22 46 30	79 00	180	" " " "
3420	" 30	22 49	79 04	190	" " " "
3421	" 30	22 49	79 07	235	" " " "
3422	" 30	22 48	79 09	235	Ot. tr., 60 ft.
3423	" 30	22 50	79 08	245	" " " "
3424	" 30	22 53 30	79 08	250	" " " "
3425	" 30	22 53 30	79 10	250	" " " "
*3426	May 1	22 52 30	79 18	235	" " 52 ft.
3427	" 1	22 52 30	79 20	240	" " 35 ft.
3428	" 1	22 52 30	79 22	240	" " " "
*3429	" 1	22 54	79 29	235	" " " "
3430	" 1	22 59	79 29	235	" " " "
3431	" 1	23 02	79 29	245	" " " "
3432	" 1	23 05	79 29	250	" " " "
*3433	" 1	23 09	79 32	250	" " " "
3434	" 1	23 10	79 35	260	" " 60 ft.
3435	" 2	23 05	79 25	255	" " " "
3436	" 2	23 05	79 28	255	" " " "
3437	" 2	23 05	79 32	260	" " " "
3438	" 2	23 05 30	79 37	265	" " " "
3439	" 2	23 05 30	79 40	295	" " " "
*3440	" 2	23 04	79 44	310	" " " "
3442	" 2	23 02	79 43	335	" " 35 ft.
3443	" 3	23 22	79 53	325	Bl. tr., 14 ft.
3444	" 3	23 22	79 53	320	" " " "
3445	" 3	23 22	79 53	330	" " " "
3446	" 3	23 21 30	79 54	360	" " " "

Station	Date	Position Latitude N.	Position Longitude W.	Fathoms	Gear
	1938	° ′ ″	° ′ ″		
3447	May 3	23 21	79 55	375	Bl. tr., 14 ft.
3448	" 3	23 21	79 56	380	" " " "
3449	" 3	23 21	79 57	390	" " " "
3450	" 3	23 20 30	79 58	390	" " " "
3451	" 3	23 20	79 59	405	" " " "
3452	" 3	23 20	80 00	400	" " " "
3454	" 4	23 24	80 36	600	" " " "
*3455	" 4	23 24	80 33	600	" " " "
3456	" 4	23 23	80 35	575	" " " "
3457	" 4	23 23	80 36	550	" " " "
3458	" 4	23 22	80 34	535	" " " "
3459	" 4	23 21	80 36	500	" " " "
*3460	" 9	23 05	81 31	240	" " 10 ft.
3461	" 9	23 06	81 29 30	205	" " " "
*3462	" 9	23 09	81 26	160	" " 14 ft.
3463	" 9	23 09	81 26	230	" " " "
3464	" 9	23 09	81 26	200	" " " "
3465	" 9	23 09	81 27	175	" " " "
3466	" 9	23 09	81 27 30	200	" " " "
3467	" 9	23 11 30	81 26	215	" " " "
3468	" 9	23 11 30	81 23	375	" " " "
3469	" 9	23 12	81 22	425	" " " "
3470	" 10	23 24	80 59	610	" " " "
3471	" 10	23 21	80 56	500	" " " "
3472	" 10	23 20 30	80 55	510	" " " "
3473	" 10	23 19	80 51	510	" " 10 ft.
3474	" 10	23 18	80 46	490	" " " "
3475	" 10	23 18	80 48	400	" " " "
3476	" 10	23 18 30	80 52	360	" " " "
*3477	" 11	23 10	81 21	195	Ot. tr., 35 ft.
3478	" 11	23 09	81 27 30	240	" " " "
3479	" 11	23 10	81 26 30	210	" " " "
3480	" 11	23 10	81 28	200	" " " "
3482	" 11	23 09	81 27 30	190	" " " "
3483	" 11	23 12	81 23	285	Bl. tr., 14 ft.
*3484	" 11	23 12 30	81 22	300	" " " "
3485	" 11	23 13	81 22	385	" " " "
3487	" 12	23 14	81 28	535	" " " "
*3488	" 12	23 11 30	81 38	515	" " " "
*3489	" 12	23 11	81 51	240	" " 10 ft.
3490	" 12	23 11	81 55	250	" " " "

Contribution No. 278

ALGUNOS FORAMINIFEROS NUEVOS DE LAS COSTAS CUBANAS*

POR JOSÉ T. ACOSTA

Museo Poey, Universidad de la Habana.

Esta modesta contribución al conocimiento de los Foraminíferos recientes de las aguas profundas que circundan a Cuba, es el resultado de estudios verificados en material obtenido durante la primera expedición a bordo del Ketch Atlantis, bajo los auspicios de las Universidades de Harvard y la Habana. Todos los ejemplares proceden de la Atlantis Sta. 2971 (Lat. 20° 34′ N., Long. 74° 24′ W.) a 810 brazas de profundidad. La muestra está constituída por una marga descalcificada de color pardo con gran cantidad de Foraminíferos perfectamente preservados, siendo a nuestro entender los que presentamos en este trabajo nuevas especies.

Los holotipos han sido depositados en la colección del Dr. Joseph A. Cushman, Sharon, Mass., y eventualmente pasarán a las colecciones de la Universidad de Harvard. Cotipos han quedado en las colecciones del Museo Poey, Universidad de La Habana; Dr. Pedro J. Bermúdez y en la del autor.

Aprovecho la oportunidad para expresar mi sincera gratitud a mi estimado maestro Dr. Pedro J. Bermúdez por su constante ayuda en mis estudios sobre los Foraminíferos cubanos.

Familia VALVULINIDAE

Género *Karreriella* Cushman, 1923

Karreriella subcylindrica (Nutall), var. **caribaea** Acosta n. var.
(Lám. 1, figs. 1-3)

Var. de *K. subcylindrica* (Nuttall), Cushman, 1937, Special Contr. no. 8, Cushman Lab. Foram. Res., p. 132, pl. 15, fig. 25.

Concha alargada, cuatro o cinco veces más larga que ancha, subcilíndrica, cuatro o cinco cámaras en la vuelta inicial, el resto tri-

* Contribution no. 278 of the Woods Hole Oceanographic Institution.

serial, terminando en dos cámaras ligeramente infladas, colocadas más o menos irregularmente, las primeras muy unidas, las últimas separadas por suturas deprimidas; pared gruesamente aenácea, con mucho cemento, superficie pulida; abertura colocada en una depresión de la cara apertural de la última cámara, con un labio prominente.

Largo, 2.0 mm.; Ancho, 0.5 mm.

Holotipo procedente de la Atlantis Sta. 2971 (Lat. 20° 34′ N.; Long. 74° 24′ W.), 810 brazas de profundidad, Costa Norte de Oriente, Cuba. Abundante.

Difiere de la especie típica en su forma más prolongada y en la posición de las cámaras.

La *K. subcylindrica* fué originalmente descrita procedente del Terciario de la Isla de Trinidad, B. W. I. Además es frecuente en las formaciones del Oligoceno y Eoceno Superior de Cuba.

Familia LAGENIDAE

Género *Chrysalogonium* Schubert, 1907

Chrysalogonium piramidale Acosta n. sp.

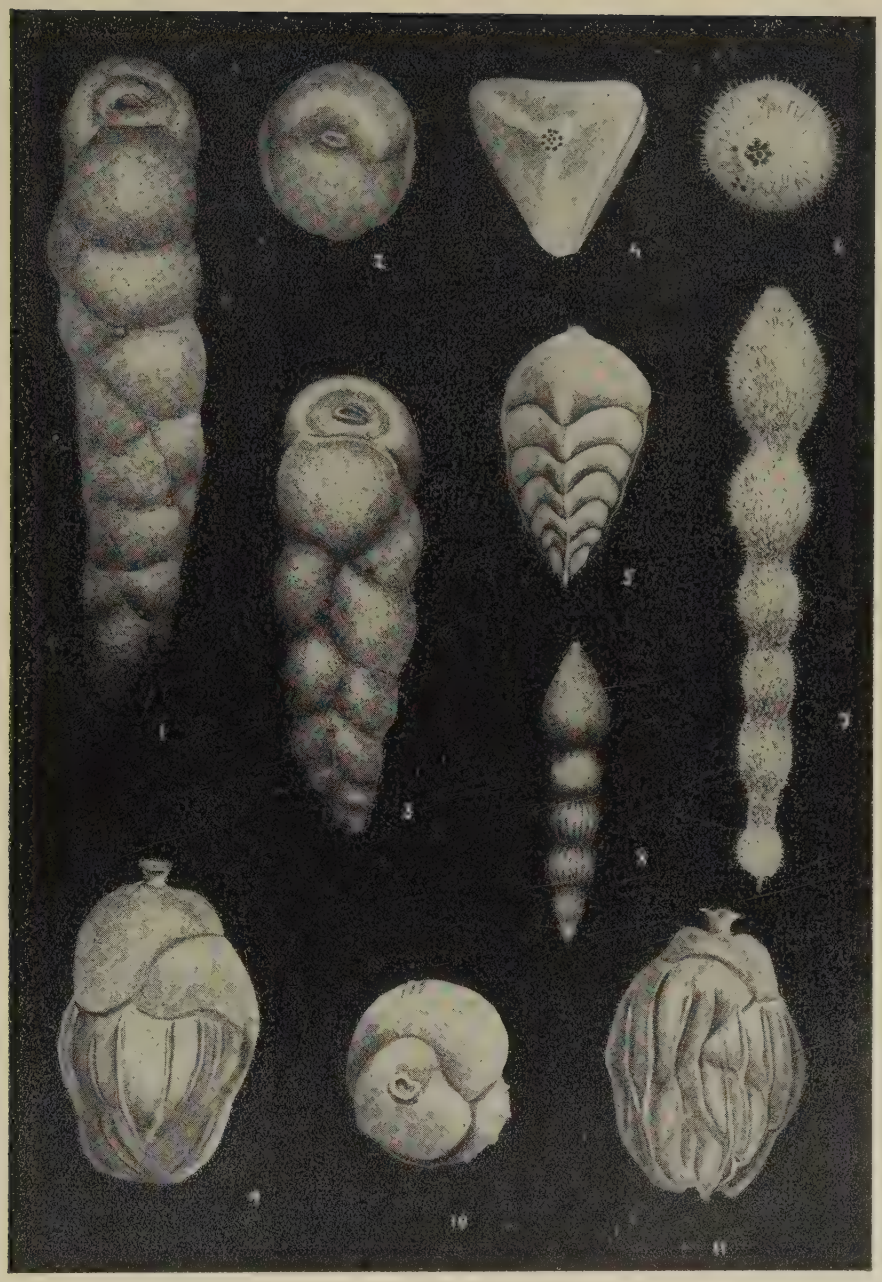
(Lám. 1, figs. 4, 5)

Concha piramidal, triangular en sección, los tres lados iguales muy ligeramente cóncavos, bordes aquillados provistos de una carina laminar y cortante, extremo apical terminado en una espinita formada a expensas de las tres carinas que convergen; cámaras numerosas, siete en el holotipo, colocadas en serie continua, siendo la primera algo globosa, el resto con las paredes planas, la última cámara abombada y sin quillas; suturas muy bien marcadas y arqueadas; pared calcárea, vítrea, de color blanco lechoso, superficie lisa y pulida; abertura terminal, formada por multitud de poros en un círculo prominente.

Largo, 0.95 mm.; Ancho, 0.5 mm.

Holotipo procedente de la Atlantis Sta. 2971 (Lat. 20° 34′ N.; Long. 74° 24′ W.), a 810 brazas de profundidad, Costa Norte de Oriente, Cuba. Raro.

Esta especie muestra bastante diferencia con los *Chrysalogonium* típicos, pero la pared calcárea, posición rectilineal de las cámaras y abertura típica del género no permiten colocarlo bajo otra denominación genérica. La peculiar forma piramidal guarda algún parecido con el género *Triplasia*, pero la abertura típicamente distinta y la pared arenácea de aquél los separan radicalmente.



FIGS. 1- 3. – *Karreriella subcylindrica* (Nuttall), var. *caribaea* Acosta n. var. ×
Fig. 1, Holotipo visto de lado; fig. 2, Cotipo vista apertural; fig. 3, Cotipo visto de lado.

„ 4- 5. – *Chrysalogonium piramidale* Acosta n. sp. ×
Fig. 4, Cotipo vista apertural; fig. 5, Holotipo vista lateral.

„ 6- 7. – *Chrysalogonium ritae* Acosta n. sp. ×
Fig. 6, Holotipo vista apertural; fig. 7, Holotipo vista lateral.

„ 8. – *Nodogenerina obsoleta* Acosta n. sp. ×
Holotipo.

„ 9-11. – *Uvigerina bermudezi* Acosta n. sp. ×
Fig. 9, Holotipo vista lateral; fig. 10, Cotipo vista apertural; fig. 11, Cotipo vista lateral.

Atlantis Sta. 2,971 (Lat. 20° 34′ N.; Long. 70° 24′ W.), 810 brazas, Costa Norte de Oriente, Cuba.

Chrysalogonium ritae Acosta n. sp.

(Lám. 1, figs. 6, 7)

Concha alargada, recta o ligeramente encorvada, cilíndrica en sección transversal; cámaras numerosas, siete en el ejemplar típico, creciendo de tamaño hacia la región apertural, la última es la mayor de todas, cámaras infladas, separadas por suturas profundas, la inicial con una espina apical prominente; pared calcárea, cubierta de espinitas irregularmente colocadas que ocupan toda la superficie de la concha; abertura terminal formada por un poro central rodeado de una serie de poros de igual tamaño que el central.

Largo, 3.0 mm.; Ancho, 0.6 mm.

Holotipo procdeente de la Atlantis Sta. 2971 (Lat. 20° 34′ N; Long. 74° 24′ W.), a 810 brazas de profundidad, Costa Norte de Oriente, Cuba. Raro.

Esta peculiar e interesante especie puede compararse con *Nodosaria* sp. B. (Palmer y Bermúdez, 1936, Mem. Soc. Cubana, Hist. Nat., vol. 10, no. 4, pág. 271, pl. 18, fig. 17); procedente del Oligoceno Inferior, Formación Adelina.

El carácter apertural de esta especie se ha notado en *Chrysalogonium elongatum* Cushman and Jarvis (1934, Contr. Cushman Lab. Foram. Res., vol. 10, pt. 3, pág. 73, pl. 10, figs. 10, 11), procedente del Mioceno Inferior de San Fernando, Isla de Trinidad, B. W. I., del que difiere por ser aquél completamente liso en tanto que nuestra especie está erizada de pequeñas espinas.

Nombramos esta especie en honor de la profesora Dra. Rita Sánchez Rojas.

FAMILIA BULIMINIDAE

Género *Nodogenerina* Cushman, 1927

Nodogenerina obsoleta Acosta n. sp.

(Lám. 1, fig. 8)

Concha fusiforme, pequeña, alargada, tenue, delgada, recta, aguzada hacia ambos extremos, circular en sección transversa, formada por multitud de cámaras uniseriales, subglobulosas, que aumentan de tamaño hacia el extremo apertural; suturas profundas, pared calcárea, vítrea, pulida, ornamentada por muchas costillas bajas que tienden a borrarse hacia las cámaras finales, desapareciendo por completo en la última; abertura terminal, simple y de forma circular.

Largo, 0.89 mm.; Ancho, 0.2 mm.

Holotipo procedente de la Atlantis Sta. 2971 (Lat. 20° 34′ N., Long. 74° 24′ W.), a 810 brazas de profundidad, Costa Norte de Oriente, Cuba. Abundante.

Esta especie difiere de todas las conocidas por carecer del labio que en ellas protege la abertura.

Género *Uvigerina* d'Orbigny, 1826

Uvigerina bermudezi Acosta n. sp.
(Lám. 1, figs. 9-11)

Concha comparativamente grande, fuerte, ancho mayor en la porción media, pocas cámaras, algo infladas, suturas profundas, visibles en la última parte de la concha, poco notables y obscurecidas por la ornamentación en la primera porción, adornada de pocas costillas salientes y cortantes que se desvanecen en las últimas cámaras dando un peculiar aspecto a la concha; pared calcárea y brillante; abertura circular, protegida por un labio hialino y situada en el centro de la última cámara.

Largo, 1.0 mm.; Ancho, 0.7 mm.

Holotipo procedente de la Atlantis Sta. 2971 (Lat. 20° 34′ N.; Long. 72° 24′ W.), a 810 brazas de profundidad, Costa Norte de Oriente, Cuba. Abundante

Esta interesante especie algo parecida a *U. barbatula* Macfadyen[1] del Mioceno de Egipto de la que difiere por su tamaño mayor, por su menor número de costillas y por la menor depresión de la porción inicial.

También guarda algún parecido con *U. semivestita* Bermúdez, del Eoceno de Cuba,[2] que se diferencia por su mayor tamaño y forma más ventruda.

Dedico esta especie a mi amigo y compañero Dr. Pedro J. Bermúdez.

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(1) Macfadyen, W. A., 1931, Geological Survey of Egypt. Miocene Foraminifera from Clysmic Area of Egypt Sinai., p. 92, pl. 3, figs. 26 a, b.

(2) Bermúdez, P. J., 1937, Mem. Soc. Cubana Hist. Nat., vol. 11, no. 3, p. 143, pl. 17, figs. 8, 9.

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FACTORS DETERMINING THE DISTRIBUTION OF POPULATIONS OF CHAETOGNATHS IN THE GULF OF MAINE[1]

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In aquatic environments, and particularly in large bodies of water, the movement of the water itself may profoundly affect both the distribution and numbers of the population. Pelagic organisms are carried with the water in its drift through each given region. Numerical abundance may thus depend on conditions in external regions from which the water comes. The moving water affects the climate of the region into which it flows, for it carries with it its inherent temperature, salinity, etc. At the same time these properties of the water may be profoundly altered in its course, through interaction with the atmosphere and with other bodies of water. The maintenance of a population in a given region under these conditions depends upon a balance of dynamic factors; the drift of the water and its interaction with its environment, as well as upon the rate of reproduction and mortality of the population under the environmental conditions determined by these circumstances (Russell, 1936). The pelagic population is at the mercy of the hydrodynamic factors, since it must move with the water. It is only by taking advantage of fortuitous hydrographic conditions, such as the existence of permanent eddies and dead waters, that they may gain a truly endemic relation to a given region.

The use of plankton as indicators of water movements has attracted deserved attention of late (Russell, 1936*a*, 1939). The effect of the circulation of water on the distribution and maintenance of permanent populations of specific organisms has received less explicit attention, but is exemplified by the studies of Damas (1905), Sømme (1933, 1934) and Redfield (1939).

As Huntsman (1919) has shown, the chaetognaths are an unusually interesting group for studies in oceanic zoögeography. Of the half-dozen species found in the coastal waters between Cape Cod and the Grand Banks, three are of deep-water origin and are drawn into the deeper basins of the Gulf as an immigrant population which perishes without reproducing. Three other species are inhabitants of the upper layers of the sea, of which one breeds endemically on the continental

[1] Contribution No. 279 from the Woods Hole Oceanographic Institution.

shelf, while the other two are immigrants from the oceanic waters offshore. These six species must have essentially similar habits of life, yet each has a characteristically different distribution, depending upon the water body in which it maintains itself endemically, and upon the degree to which these waters are drawn into the various regions of the coast. The value of Sagittae as indicators of water movements in British waters has been demonstrated by Russell (1935, 1936*b*), Fraser (1937, 1939) and Pierce and Orton (1939).

The present paper is an examination of the populations of chaetognaths found in the Gulf of Maine during the year 1933–34, when the research vessel of the Woods Hole Oceanographic Institution, the "Atlantis," made a systematic survey of the region. While the results confirm in the main the observations of Bigelow (1926) in this region and

TABLE I

Statistics of collections of chaetognaths in the Gulf of Maine, 1933–1934.

Dates of Cruise	Number of Stations at Which Chaetognaths were Present						
	S. elegans	*S. serratodentata*	*S. maxima*	*S. lyra*	*S. enflata*	*E. hamata*	Total Stations
Sept. 2–14, 1933	30	12	6	2	1	14	35
Dec. 2–11, 1933	17	9	5	1	0	13	22
Jan. 3–13, 1934	11	7	2	2	0	9	12
Mar. 21–28, 1934	10	8	0	0	0	15	18
April 17–May 13	20	9	2	0	0	16	32
May 21–June 2	32	20	4	1	0	21	44
June 25–July 1	6	2	0	0	0	2	7
Sept. 17–24, 1934	20	16	4	3	1	15	25
Total	146	83	23	9	2	105	195
Per cent present	75	43	12	46	1	54	

Dates of Cruise	Numbers of Chaetognaths Taken at These Stations						
	S. elegans	*S. serratodentata*	*S. maxima*	*S. lyra*	*S. enflata*	*E. hamata*	Total
Sept. 2–14, 1933	2,961	104	9	4	2	107	
Dec. 2–11, 1933	3,608	45	17	1	0	300	
Jan. 3–13, 1934	194	8	3	3	0	87	
Mar. 21–28, 1934	105	13	0	0	0	95	
April 17–May 13	785	137	8	0	0	274	
May 21–June 2	1,698	104	21	2	0	289	
June 25–July 1	368	33	0	0	0	2	
Sept. 17–24, 1934	453	534	5	3	5	133	
Total	10,170	978	63	13	7	1,287	12,418
Per cent of total	82	7.9	0.51	0.10	0.06	9.5	—

Dates of Cruise	Mean Catch per Haul at Stations at Which the Species was Present						
	S. elegans	*S. serratodentata*	*S. maxima*	*S. lyra*	*S. enflata*	*E. hamata*	Total
Sept. 2–14, 1933	98.7	8.7	1.3	2.0	2.0	7.6	
Dec. 2–11, 1933	212.0	5.0	3.4	1.0		22.1	
Jan. 3–13, 1934	17.6	1.1	1.5	1.5		9.7	
Mar. 21–28, 1934	10.5	1.6	—	—		6.3	
April 17–May 13	39.1	15.2	4.0	—		17.0	
May 21–June 2	53.0	5.2	5.3	2.0		13.7	
June 25–July 1	61.5	16.5	—	—		1.0	
Sept. 17–24, 1934	22.7	33.4	1.25	1.0	5.0	8.9	
Mean catch per haul for entire period	69.8	11.8	2.74	1.44	3.5	11.3	

Dates of Cruise	Per Cent of Total Hauls in Each Period at Which Each Species was Present						
	S. elegans	*S. serratodentata*	*S. maxima*	*S. lyra*	*S. enflata*	*E. hamata*	Total
Sept. 2–14, 1933	86	34	17	5.7	2.9	40	
Dec. 2–11, 1933	77	41	23	4.5		59	
Jan. 3–13, 1934	92	58	17	17		75	
Mar. 21–28, 1934	56	45	0	0		83	
April 17–May 13	63	28	6.3	0		50	
May 21–June 2	73	45	9	2.3		48	
June 25–July 1	86	29	0	0		14	
Sept. 17–24, 1934	80	64	16	12	16	60	
Entire period	75	43	12	4.6	1	54	

of Huntsman (1919) in Canadian waters, it has seemed worthwhile to examine them together with those of Bigelow and Huntsman from the point of view outlined above.

Material and Data

General Statistics

The cruises were planned to include lines of stations extending from shoal water across the Gulf so as to sample all the principal parts of the Gulf and the enclosing banks. While exigencies of weather and the loss of nets interfered with the completeness of the program, the 195 hauls included in this study amount to a fairly satisfactory random sampling of the region, throughout the year.

The collections were made with a standard 1.5 meter Heligoland larva net (No. 0 silk, 38 meshes to the inch) drawn vertically from a point near the bottom to the surface. The opening of the net had an area of 1.7 square meters. Table I contains some statistical data on the collections.

Numerical Abundance.—The 12,418 specimens taken give a mean catch of 64 per haul or 37.5 per square meter of sea surface. Of these by far the most abundant was *S. elegans,* amounting to 82 per cent of the total. With *S. serratodentata* yielding 7.9 per cent, these two shallow-water forms accounted for 90 per cent of the total population. Of the three deep-water species *E. hamata* accounted for 9.5 per cent of the catch, with *S. maxima* and *S. lyra* making up 0.5 and 0.1 per cent respectively.

FIG. 1

FIG. 2

FIG. 1. Locations at which *Sagitta maxima* has been taken in the Gulf of Maine.

FIG. 2. Locations at which *Sagitta lyra* has been taken in Gulf of Maine. Figures in circles indicate the numbers taken per haul from "Atlantis" in 1933–34. Solid circles indicate Bigelow's captures.

The relative breadth of distribution of the species is indicated by the percentage of stations at which each was taken. The general order is the same as for the numerical abundance. The species differ, however, far less in distribution than in numerical abundance, e.g., *S. serratodentata* and *E. hamata* which accounted for only 8 and 9 per cent of the total numbers but occurred at more than 40 and 50 per cent of the stations.

Numerical abundance depends on both the extent of distribution and the density of population within that distribution. A general idea of the latter is given by the mean size of the catch at each station at which a given species is present. Again the order is essentially the same, *S. elegans* leading with a mean density of 70 per haul, *S. serratodentata* and *E. hamata* following with 12 and 11 per haul, while *S. maxima* and *S. lyra* occur sparsely when at all.

Seasonal Fluctuations

Sagitta elegans and *S. serratodentata* show a decline in total numbers taken, and in the mean density of the population at the stations where they were present during the colder part of the year. The figures are irregular as both forms occur occasionally in dense swarms, but it appears that these species are reduced to perhaps one-tenth their numbers during the winter. The cruises in December, January and March did not sample adequately the waters of Georges Bank where the larger catches of *S. elegans* were taken at other seasons and this may exaggerate the apparent effect of winter on this species, although it can scarcely do so in the case of *S. serratodentata,* which occurs chiefly over the deeper part of the basin which was adequately sampled.

Contrasted with these inhabitants of the upper levels, in which the seasonal change in temperature is great, the deep-water species *E. hamata* shows no systematic fluctuation either in total numbers, the percentage of stations at which it is present, or numbers taken per haul, during the year. Bigelow (1926) has pointed out that this is to be expected since the depths at which it lives are not subject to much change in temperature.[2]

The Distribution of the Deep-Water Species

Sagitta maxima, S. lyra and *Eukrohnia hamata* are inhabitants of the deeper waters of the Gulf of Maine. Figures 1 and 2 record the location and numbers of the two former species taken in each haul while Fig. 3 shows the general pattern of distribution of the more abundant *E. hamata.* All our specimens of *S. maxima* were taken in water of over 170 meters depth and it occurred in greatest abundance in depths of over 200 meters. It seems safe to conclude with Huntsman and Bigelow that it occurs only in the deeper parts of the Gulf, chiefly below the 150-meter level. The distribution of the catches of *S. lyra* is essentially the same as that of *S. maxima.* The regional occurrence of *E. hamata* is similar to that of the deep-water sagittae, though it was taken more frequently in the shoaler regions along the margins of the Gulf, occasionally in water of as little as 100 meters depth. It appears to occur rather nearer the surface than do the deep-water sagittae.

The distribution of catches of the three species agree in showing the highest frequency of successful catches and the greatest numbers per haul in the Eastern Channel through which deep water has access to the Gulf. Inside the Gulf the populations are concentrated in the eastern

[2] Bigelow considered that *S. maxima* occurred in the Gulf more frequently in winter, *S. lyra* in summer. Our data do not confirm this. Their numerical abundance is rather closely correlated throughout the year and neither shows a clear seasonal variation.

basin, and diminish in abundance northward and westward as the Eastern Channel becomes remote.

Dynamic contours give the best available information concerning the probable circulation of the deeper water. Contours representing the circulation at 140 meters in May–June, 1934 are indicated in Fig. 5.[3] They represent a pattern which occurs with some variation in detail from month to month at this and greater depths. The center of abundance of the three deep-water chaetognaths lies in the rapidly moving inflow or in the eastern side of the eddy which has its vortex in the deep basin northwest of the Eastern Channel. Once the creatures pass beyond the vortex they become scattered and decrease in numbers.

The distribution of the deep-water chaetognaths suggests strongly that they are carried into the Gulf from offshore, along with the warm

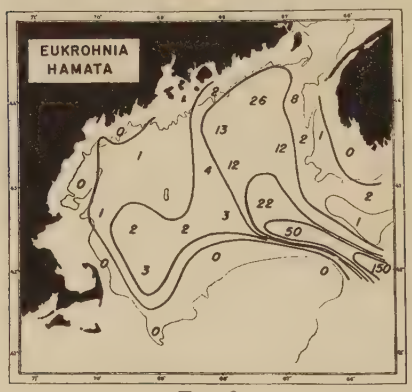

FIG. 3

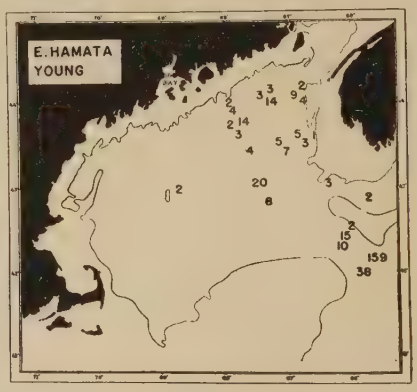

FIG. 4

FIG. 3. Relative abundance of *Eukrohnia hamata* in different parts of the Gulf of Maine. Numbers represent the average catch per haul in various regions.

FIG. 4. Locations at which young specimens of *Eukrohnia hamata* were taken in 1933–34. Numbers indicate the number of young taken per haul at each position.

saline water which Bigelow (1927) found to enter through the Eastern Channel. Since there is no evidence that they breed within the Gulf, they are to be considered as terminal immigrants from other regions in which they breed endemically. While some of those which are carried into the Gulf may complete the circuit of the eddy and be carried out again, the greater number are probably trapped within the dead waters of the inner Gulf, live as long as circumstances permit and die without leaving progeny.

The foregoing observations and conclusions are in entire agreement with those of Bigelow (1926). In certain details, however, our findings

[3] A hydrodynamic analysis of the circulation of the Gulf of Maine during the period of our survey is being prepared by Dr. E. E. Watson, to whom I am indebted for the use of this and subsequent figures.

differ from his. While he considered *E. hamata* to occur with regularity throughout the year, the sagittae were thought to fluctuate with the season, *S. maxima* being taken predominantly in the colder part of the year and *S. lyra* in the warmer. He proposed that *S. maxima,* an inhabitant of northern waters, is barred from the Gulf by the warmth of the water entering the Eastern Channel during the summer months. The statistics recorded in Table I fail to show a clear fluctuation in any of the deep-water species which may be correlated with the season. That *S. maxima* may enter the Gulf at a time when the water is warmest is evidenced by our taking 12 and 6 specimens in two hauls made in the Eastern Channel in May when the temperature of the deeper water was 8°–9° C. and 2 in a September haul from water varying in temperature from 6.5° to 8.76°.

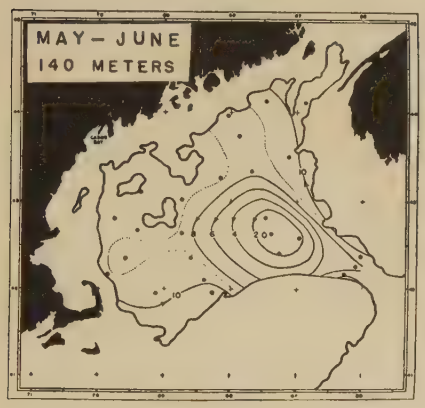

FIG. 5

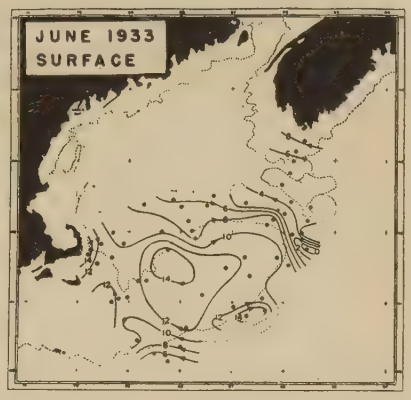

FIG. 6

FIG. 5. Dynamic contours indicating theoretical circulation in the basin of the Gulf of Maine at depth of 140 meters in May–June, 1934.

FIG. 6. Dynamic contours indicating theoretical circulation at surface of Georges Bank in June, 1933.

We believe he was misled, particularly in the case of *S. lyra,* of which he took only 6 examples, by the fact that his cruises did not sample the center of abundance of the populations as thoroughly as the more remote and colder periphery of the range.

Factors Limiting the Distribution within the Gulf

In attempting to evaluate the relative importance of the circulation of the water and of environmental factors in determining the abundance and distribution of the species, it is crucial to inquire whether the numerical relations are due to the degree to which the three species are "adapted" to the conditions in the Gulf, or whether they are to be explained by the relative numbers in which they enter from offshore.

In the former case the numerical ratios should shift as one compares waters increasingly remote from the point of entrance. In the latter they should remain unchanged.

To examine these possibilities, we have divided the catches in which any of the species occurred into three groups: (1) those taken in the deep water of the Eastern Channel (east of 66°30′ and south of 42° 40′N); (2) those lying immediately within the basin (a quadrangle lying between 42°10′ and 43°30′N and 66°30′ and 67°30′W), and (3)

TABLE II

Relative numbers of deep-water chaetognaths taken in different areas in Gulf of Maine.

Total Numbers	*E. hamata*	*S. maxima*	*S. lyra*
Eastern Channel	434	34	2
Southeastern quadrangle of basin	411	25	6
Remainder of basin	442	4	5
Total area	1287	63	13
Relative Numbers Taken			
Eastern Channel	100	7.8	0.5
Southeastern quadrangle of basin	100	6.1	1.5
Remainder of basin	100	0.9	1.1
Total area	100	5.0	1.0
Stations Present			
Eastern Channel	9	6	1
Southeastern quadrangle of basin	19	11	3
Remainder of basin	87	5	5
Total area	105	23	9
Relative Numbers of Stations Present			
Eastern Channel	100	67	11
Southeastern quadrangle of basin	100	58	5.7
Remainder of basin	100	5.7	5.7
Total area	100	22	8.6

the remainder of the Gulf. These three areas yielded *E. hamata* in about equal numbers. They differ in proximity to the external sources of the deep water of the Gulf.

The numbers of specimens and the relative numbers of each species taken in these areas are given in Table II. They show that a great disparity between the abundance of the three species already occurs in the water entering the Channel. In the main the relative abundance is established by conditions external to the Gulf, and cannot be attributed merely to the selective effect of conditions within.

There is, however, clear evidence that some selective mechanism is at work limiting the penetration of *S. maxima* into the remoter region. The ratio in which *S. maxima* is taken in proportion to the catch of *E. hamata* is eight times as great in the Eastern Channel as in the remoter region. The distribution of *S. lyra* appears to resemble that of *E. hamata* more closely than that of *S. maxima*.

TABLE III

Catches of Sagitta maxima and Sagitta lyra classified according to highest temperature of the water column (below 100 meters) from which they were taken.

Temperature, ° C.	*S. maxima*							
	5–5.5	5.5–6.0	6.0–6.5	6.5–7.0	7.0–7.5	7.5–8.0	8.0–8.5	8.5–9.0
Number per haul	1	1 1	2	3	2 2 1 1 1	6 2 1	12 6 6 3 2 1	6 2
Total	1	2	2	3	7	9	30	8
Per cent of total	1.59	3.18	3.18	4.76	12.7	14.3	47.7	12.7
Integrated per cent	1.59	4.77	7.95	12.71	25.4	39.7	87.4	100
Mean catch per haul	1	1	2	1.5	1.3	3	5	4

Temperature, ° C.	*S. lyra*							
	5–5.5	5.5–6.0	6.0–6.5	6.5–7.0	7.0–7.5	7.5–8.0	8.0–8.5	8.5–9 0
Number per haul					1 1 1 1	1	3 2 2 1	
Total	0	0	0	0	4	1	8	
Per cent of total	0	0	0	0	30.8	7.7	61.6	
Integrated per cent	0	0	0	0	30.8	38.5	100	
Mean catch per haul	0	0	0	0	1	1	2	

In the discussion of the geographical distribution of the chaetognaths,—as of marine plankton in general,—temperature and salinity are commonly considered as factors limiting the distribution of the species. The water in which the chaetognaths of the depths appear to be carried as they penetrate the Gulf undergoes admixture with subsurface layers. As a result it becomes colder and less saline. While not wishing to suggest that these factors are not in a broad way influential in determining the survival of the species, we do wish to question whether they, or

similar environmental conditions, are essential in accounting for the differences in their distribution within the Gulf of Maine. While our data suggest that *E. hamata* invades colder water more frequently than *S. maxima* and *S. lyra,* there is no evidence that these latter cannot survive in water at least as cold as any in which we have taken the former species. Bigelow (1926, p. 325) records captures of *S. maxima* off the continental slope in waters of 3° to 6° C. and considers this species to be a distinctly cold-water form. *S. lyra* was taken by him in water of 6° C.—below which only 8 per cent of the total catch of *E. hamata* was taken. Though it may be considered a creature of relatively warm water, we have shown that it penetrates into the colder parts of the Gulf, relatively as frequently as does *E. hamata.*[4]

We believe the disparity in distribution of the deep-water chaetognaths in the Gulf can be explained more readily in another manner. We have presented in Tables III and IV data showing the incidence of

TABLE IV

Catches of Eukrohnia hamata classified according to highest temperature of the water column (below 100 meters) from which they have been taken. Total catch = 1287.

Temperature, ° C.	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11
Total hauls	7	13	15	32	40	28	11	4	1
Total caught	7	11	33	61	213	407	310	244	1
Per cent of total	0.54	0.86	2.56	4.74	16.5	31.5	24.0	18.9	—
Integrated per cent	0.54	1.40	3.96	8.70	25.2	56.7	80.7	99.0	100
Mean catch per haul	1.0	0.85	2.2	1.9	5.3	14.5	28.2	60	1

the species in water of different maximal temperatures. The catches have been classified according to the temperature of the water in which they were taken. We have chosen the highest temperature recorded below 100 meters, since there is no way of knowing the level at which an animal caught in a vertical haul is taken, and since this temperature will represent the least departure from the condition under which the water entered the Gulf. The temperature profiles shown in Fig. 7 give

[4] Salinity cannot readily be separated from temperature as a possible limiting factor within the deep water of the Gulf because variations in temperature and salinity alike are due to mixtures in varying proportion of the deep, warm, and saline water with the superficial, cold, and dilute water. As a result, the temperature-salinity diagram for waters in all parts of the Gulf below the level of homogeneous winter mixing is almost a straight line and is nearly the same in each region.

It is, moreover, extremely difficult in view of what is known experimentally concerning the osmotic regulation of marine invertebrates, to believe that changes of one or two parts per mille would vitally affect animals native in 34 or 35 ‰ salinity.

some idea of the possible range of temperature in various regions of the Gulf.

Tables III and IV show the result of this classification. Though not corrected for the relative number of hauls taken in each kind of water, this correction may be neglected in comparing the different species since the data for each are derived from the same collection of catches. For each species the numbers fall off sharply as the temperature declines. In the case of *S. maxima* and *S. lyra* the great change occurs at about 7° C. *E. hamata* appears to succeed better in penetrating the colder parts of the Gulf, the numbers caught falling markedly only below 6° C.

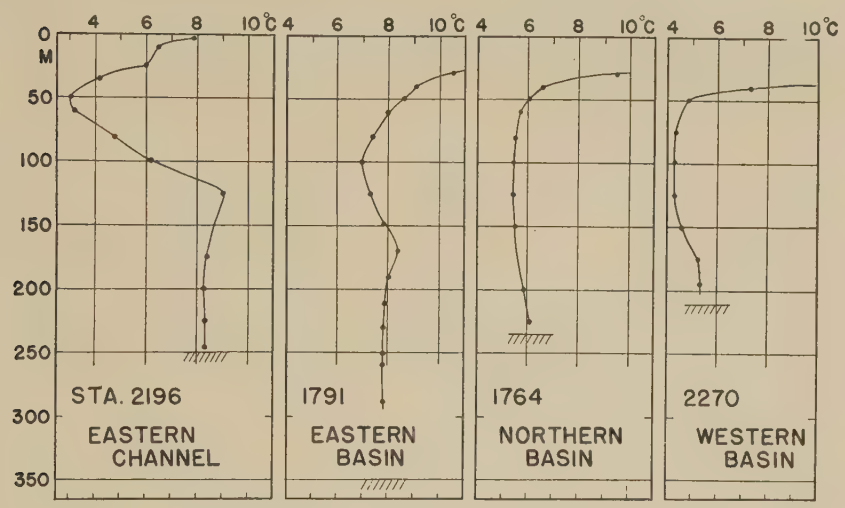

FIG. 7. Distribution of temperature with depth at a number of stations at which *Sagitta maxima* was taken.

In Fig. 8 we have plotted the integrated data showing the fraction of the total catch of each species which has penetrated to regions of decreasing temperature. The curves in Fig. 8 might be interpreted as representing the relative tolerance of individuals of the three species for the physical characteristics of the water. When the dynamic nature of the situation is considered, we believe they may be more plausibly interpreted as depending on the time of survival to be expected by the numbers which enter the Gulf, and irrespective of any change in the physical characters of the environment to be encountered therein except insofar as the conditions in the Gulf are unsuitable for its reproduction. Since the changes in the physical characteristics of the deep water depend on mixing processes, and since these must proceed relatively uniformly in all parts, the change in temperature and salinity is a function of the

time during which the water has been exposed to these processes. Temperature and salinity are thus a function of the age of the deep water in the Gulf. The abscissa of Fig. 8 may be replaced by a time scale reading from right to left and measuring in a general way the time since the water with its included population entered the Gulf.

With these considerations in mind, the curves in Fig. 8 may be interpreted as probability integrals representing the expectancy of life of the groups of chaetognaths which appear in the Eastern Channel. *E. hamata* has an expectancy of longer life than the others. Hence it has time to be carried into the remoter parts of the Gulf in large numbers

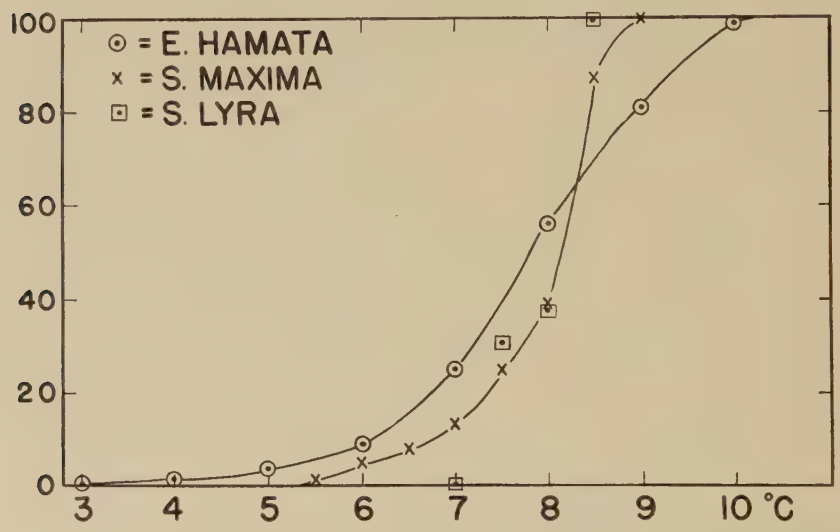

FIG. 8. Percentage of the total catch of *Eukrohnia hamata, Sagitta maxima* and *S. lyra* taken at stations at which the water below 100 meters was colder than the temperature shown on the abscissa. Based on integrated percentages shown in Tables II and III.

before it dies. Why its expectancy is longer may depend merely on its inherent longevity. It may, however, depend on its relative age at the time when it enters the Gulf. For the latter alternative there is some evidence, for we have found that young individuals of this species appear in the eastern side of the basin during the winter months (Fig. 4). This interpretation renders any special considerations of the relative fitness of the environment for the three species unnecessary, though it does not exclude them as contributory causes.

The distribution within the Gulf appears to depend essentially upon the current system and upon the age of the population which enters the region. This in turn must depend upon the relative remoteness from

the Eastern Channel of the centers of reproduction for each species—a remoteness to be measured in terms of the length and velocity of the transport system which bears the population to its destination.

The Sources of the Deep-water Population

Turning to the external sources of the population which enter the Gulf, the question is: Do the different species have a common source in the slope water which enters the Eastern Channel, or do they come from different sources to be mingled during their passage into the Gulf? The first alternative demands the same relative abundance of the species in the slope water as within the immediate entrance of the Gulf. Huntsman records catches of chaetognaths from 20 stations along the coast of the maritime provinces in water of over 1,000 meters depth made with vertical hauls from depths between 200 or 375 meters and the surface. In these hauls he counted 408 *E. hamata,* 235 *S. maxima,* and 49 *S. lyra.* The numerical ratios are 100 : 59 : 12. The relative abundance of *S. maxima* and *S. lyra* are almost the same as their occurrence in the Gulf of Maine. *E. hamata* was, however, very much scarcer relatively in these collections than in those made in the Gulf of Maine and was absent from a number of stations at which the others occurred. If Huntsman's catches may be considered characteristic of the slope water to the eastward of the Eastern Channel, then this body—at least in its upper layers—cannot be considered the sole source of the *E. hamata* population of the Gulf of Maine.

Bigelow considered *S. maxima* to come to the Gulf of Maine with the slope water from the northeast. He suggests that *E. hamata* is confined to waters so deep, except in high latitudes, that it never reaches the Gulf of Maine from the oceanic basin abreast of it, a consideration which seems to limit its origin also to the slope water. The absence of *S. lyra* from Huntsman's inshore and eastern stations, together with its more limited distribution in the north Atlantic, seem to preclude its origin from the boreal sources of the slope water. Since Huntsman's and Bigelow's studies were published, Rossby (1936) has shown that there are important forces at work transporting deep oceanic water into the region of the slope water, as the result of which this body owes its origin to oceanic as well as to boreal sources. Redfield (1936) has discussed the ecological consequences of these facts. The diverse origin of the waters which enter the Gulf of Maine and their inhabitants are thus more clearly understood. Hydrographic observations emphasize the complexity of the water bodies occurring close to the mouth of the

Eastern Channel. These facts seem to favor a diversity in the origin of the chaetognaths which penetrate the Eastern Channel.[5]

The Distribution of the Chaetognaths of the Upper Levels

Sagitta enflata, S. serratodentata, and *S. elegans,* all of which are more commonly taken in tows from the upper 100 meters, present much greater contrasts in numbers, distribution, and seasonal fluctuations than do the deep-water chaetognaths. Their occurrence and abundance can be attributed to the circulation of water and its relation to the areas suitable for their reproduction in great detail. On the one hand, *S. elegans* is capable of reproducing in the shallow waters which encircle the Gulf and occurs in numbers and at times which can be attributed to the nature and stability of local hydrographic conditions. On the other hand, *S. serratodentata* is an inhabitant of the warm ocean offshore and is carried into the Gulf as a periodic immigrant at times dependent on a cyclic change in the major circulation of the region, while *S. enflata* represents a rare straggler from (hydrographically) more remote regions which can reach the margins of the Gulf only at such times as the temperature of the water permits its survival for a sufficient period.

Sagitta enflata

S. enflata is a tropical form ranging to 40°N in the surface water of the Gulf Stream. Huntsman found it only at the outermost stations along the continental margin and in considerable numbers only at his more western stations in the offing of the Eastern Channel. He captured one specimen in July over the coastal shelf north of Sabro Bank. It has been taken occasionally over the continental slope south of Cape Cod, Bigelow and Sears (1939) recording a large catch of juveniles close to Martha's Vineyard in 1935. South of Delaware it is not infrequent 30 miles in from the continental slope and south of the Chesapeake it occurs frequently close in to land. The invasion of the coastal waters south of Cape Cod occurs at all seasons but most often in the autumn. We captured *S. enflata* on two occasions only. On September 3, 1933

[5] Bigelow found *E. hamata* to vary markedly in abundance from season to season, a fact which might arise from variations in the inflow and its origin from year to year. His capture of *S. maxima* chiefly in winter and *S. lyra* in summer, as well as our failure to find these species dissociated in time may have their origin in similar fluctuations. Bigelow concluded, from hydrographical evidence, that the inflow through the Eastern Channel is variable. Our data have been searched for correlations between the distribution of the species and that of the hydrographic factors in the region of the Eastern Channel, but we have failed to find any good evidence of a dissociation in the time at which the different species enter or in their presence in separate bodies of water within the neighborhood of the Eastern Channel.

one specimen occurred in a haul made in the South Channel in association with large numbers of salpae. On September 23, 1934 five specimens occurred in a haul taken well within the Eastern Channel.

S. enflata is thus one of the many tropical forms which in small numbers find their way in over the margin of the continental shelf in the latter part of each summer. Our records are the first for the margins of the Gulf itself. In the present connection the species is of interest as the extreme example in a series of forms relating frequency of occurrence to the remoteness of the area of reproduction, and to seasonal fluctuations.

S. serratodentata Krohn

This inhabitant of the upper layers of the warmer parts of all oceans extends farther north than most such, being able to survive, though not to breed, in relatively cold water and consequently it extends farther inshore than do most forms of like origin. Huntsman found *S. serratodentata* at practically all stations off the continental slope as far east as the Newfoundland Banks. It extended into the Laurentian Channel over the deep trough but did not penetrate into the Gulf of St. Lawrence. It occurred over the western half of the Nova Scotian Banks well in toward shore and in numbers increasing westward. Bigelow records its occurrence off the continental shelf to the south of Georges Bank and states that from New York southward it is the prevailing chaetognath right in to the shore in warm summers, though outnumbered by *S. elegans* in cooler seasons, at least over the inner part of the shelf as far south as Delaware Bay. North of Chesapeake Bay, and especially east of New York, it is much less frequent close to the land. Bigelow and Sears (1939) find no seasonal fluctuation in its abundance, either inshore or offshore in the coastal belt west of Cape Cod. They consider it to be maintained by local reproduction within that area.

In the Gulf of Maine Bigelow (1926) found it to penetrate the eastern part of the basin regularly and to extend westward along the New England coast in diminishing numbers as far as Massachusetts Bay. He took it only occasionally in small numbers on Georges Bank. It was absent from the southwestern quarter of the basin at all times and disappeared almost completely from the entire Gulf in the late autumn. Its occurrence was highly seasonal, the invasion of the Gulf beginning in late spring and culminating in September. There is no evidence that it reproduces successfully in the Gulf.

Our collections confirm abundantly Bigelow's general conclusions. The center of abundance is in the eastern half of the Gulf, agreeing well with that of the deep-water chaetognaths, though extending into the

shoaler water over Brown's Bank and the Northern Channel. Access to the Gulf is available over this route from the concentrations Huntsman observed on the western Nova Scotia Banks and from the slope water over the Eastern Channel. The inner and western part of the Gulf is penetrated in smaller numbers and in general along the northern side of

FIG. 9. Locations at which *Sagitta serratodentata* has been taken in the Gulf of Maine at different times of year. Figures in circles represent numbers taken per haul. Small circles represent positions of hauls in which none were taken.

the Gulf. Only in isolated cases were small numbers taken within the 100-meter contour or from the deep basin south and west of Cashes Ledge.

The seasonal picture during 1933–34 is given by Fig. 9, showing the combined catch in cruises grouped according to the time of year. Between January and March the population was at its low ebb, the distribu-

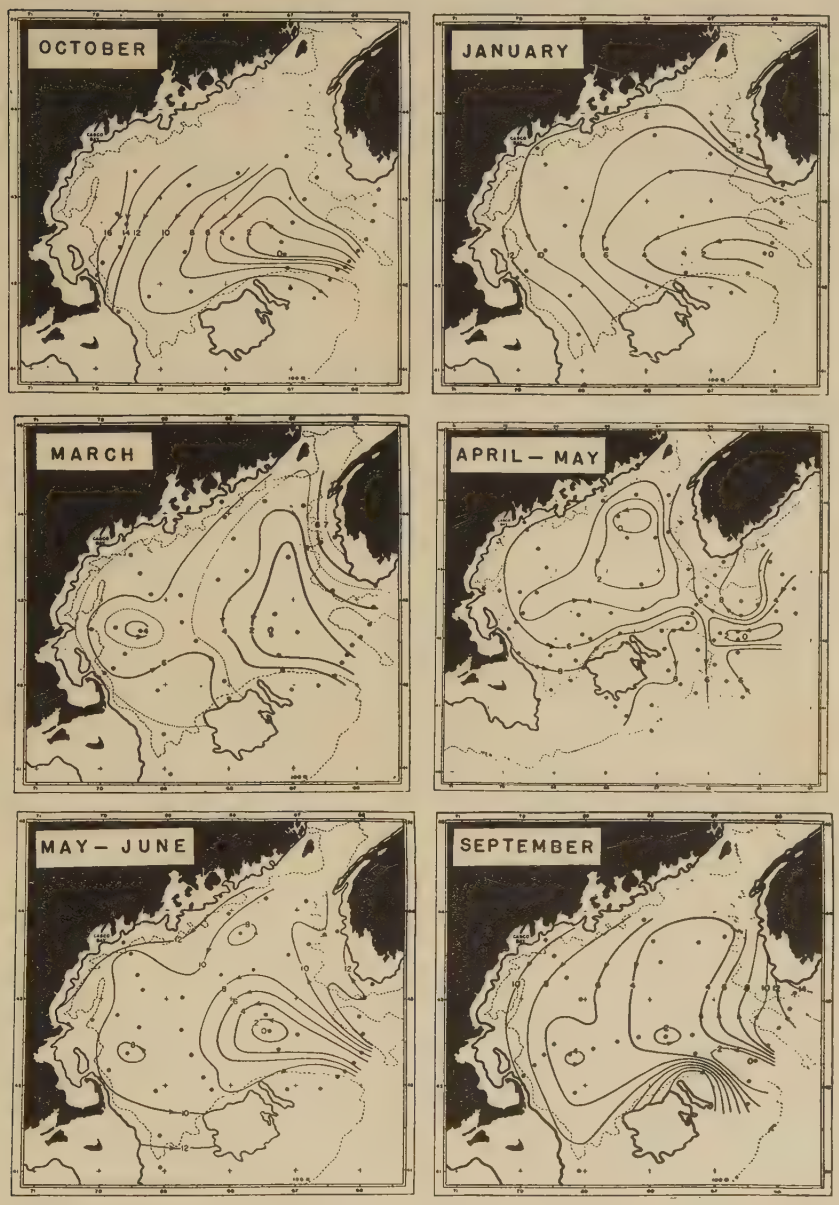

FIG. 10. Dynamic contours showing the theoretical circulation in the Gulf of Maine at a depth of 40 meters from October, 1933 to September, 1934.

tion was almost uniform throughout the Gulf. Such concentration as existed occurred in the northeastern quarter. By April and May the species had disappeared from the western side of the Gulf almost completely, but a new invasion was apparent from the southeast. By September the numbers had increased in this area of concentration and smaller numbers had extended westward as far as Portland while scattered individuals had again reached the remoter parts of the Gulf. By December the inflow of water carrying *S. serratodentata* appeared to have ceased and the remnants of the earlier invasion remain in small numbers still concentrated in the eastern region.

The course taken by *S. serratodentata* in its invasion of the Gulf is that expected of superficial water, entering from the outer Scotian Banks, in its circuit of the Gulf. It follows closely the drift of the population of *Limacina retroversa* which entered the Gulf in December, 1933 and circumnavigated the entire basin (Redfield, 1939). Unlike *Limacina,* this sagitta population did not survive to reach the western basin in significant numbers, and it was rarely found in the southwestern quarter, where lies the most ancient water in the Gulf. It also differed from *Limacina* in invading the Gulf continuously from late April through September.

Bigelow pointed out that neither temperature nor salinity explains the disappearance of *S. serratodentata* in the fall. The water is considerably warmer in November than it is at the time when invasion commences in the spring. Salinity is not very different then from that in late summer. He suggests that increases in numbers in the summer mirror the accumulation of a population which finds conditions favorable there. With the cessation of the invasion in autumn, the visitors of the summer die off from natural causes, leaving no progeny and so the species disappears until new immigrants enter in the spring. This explanation is clearly in accord with the picture we have obtained of the deep-water chaetognaths, save for the periodic character of the invasion.

Bigelow (1926) proposed that the periodic invasion of *S. serratodentata* may be connected with the seasonal reproductive cycle. The lack of any seasonal fluctuations in the numbers taken on the coastal belt west of Cape Cod, subsequently remarked by Bigelow and Sears (1939), leads us to suspect that the periodicity in the Gulf of Maine is due to a periodic change in the circulation of water, rather than to the seasonal character of the reproductive cycle.

The center of reproduction of *S. serratodentata* must lie in the warmer waters east of the continental slope, from which they penetrate the slope water and ultimately reach the Gulf in the indraft over the Eastern Channel. The dynamic contour charts (Fig. 10), showing the

theoretical pattern of circulation in the superficial layers, show that in April–May, 1934 an extensive area of dead water appears to occupy the banks south of Nova Scotia, and that the only apparent movement into the Gulf is from the continental margin off the Eastern Channel. In late May and through October this offshore indraft strengthened, thus supplying the required medium for the invasion of *S. serratodentata* into the Gulf. During the winter months the circulation of sub-surface water into the Gulf alters the contours indicating a much more intense flow across the Scotian Banks. Bigelow (1927) has shown that this change occurs with regularity and results in a regular invasion of water of low temperature and salinity. Such a flow will supply the Gulf with water derived from the inner and more eastern regions of the Scotian Banks where, according to Huntsman (1919), *S. serratodentata* is absent even in summer. During the winter months the invasion of this species into the Gulf will be checked and the population will decline until the inflow of this barren water across the Banks is checked, as it was in April–May, and the offshore indrift becomes predominant.

Sagitta elegans

Sagitta elegans Verrill is the most interesting member of the group because it is the only one maintaining a center of reproduction within the area. It is the characteristic sagitta of the north Atlantic coast, being of general occurrence in the shoaler water. Huntsman found it generally distributed in Canadian waters as far east as the Grand Banks, with particular abundance over the deeper parts of the coastal banks. Offshore it occurs only sparsely beyond the 100-meter contour. Georges Bank is the most southern important center of reproduction, though it ranges south as far as Chesapeake Bay in some seasons (Bigelow and Sears, 1939). In the Gulf of Maine Bigelow found *S. elegans* to occur most plentifully on Georges Bank, in the North Channel and on the adjoining banks south of Cape Sable, in Massachusetts Bay and in smaller numbers along the coast of Maine and New Hampshire within the 100-meter contour. Over the deep basin it is at all times much scarcer. This species becomes very scarce in most parts of the Gulf in early spring. Particularly, in Massachusetts Bay, where dense populations occur in the late summer, it almost entirely disappears in late winter.

Our collections confirm in detail the general features of the distribution of *S. elegans* in the Gulf of Maine described by Bigelow. By combining our data with his records for vertical hauls, and by grouping the two sets of observations by periods in which the findings are essentially

concordant, we are able to give in Fig. 11 a more detailed picture of the seasonal distribution than appeared from his analysis.

Georges Bank was the principal area of abundance of *S. elegans,* both in extent and density of population. Catches of hundreds or thou-

FIG. 11. Locations at which *Sagitta elegans* has been taken in the Gulf of Maine at different times of year. Upright figures represent numbers taken per haul by "Atlantis" in 1933–34. Italic figures represent numbers taken by Bigelow in vertical hauls. Contours enclose areas in which not more than ten specimens per haul were taken.

sands were taken there at all times of year. The area was not adequately explored during the winter months but on the eastern end, at

least, the catches were as abundant then as at any other time. One catch of 3,500 was made in December. The greatest abundance was observed in July.

The Scotian banks south of Cape Sable and the waters over the North Channel was the second area of abundance. In midsummer, catches were obtained there equalling those on Georges Bank. The numbers were less permanent, however, declining in late summer and becoming scanty during the winter period. Recovery was not indicated before May. This area appears to be an extension of the center of abundance which Huntsman (1919) observed on the western Nova Scotia banks in July.

Massachusetts Bay and the coastal waters extending eastward to the Bay of Fundy form an area of intermediate abundance, marked by great seasonal fluctuation. In winter *S. elegans* was rare in these waters with only scattered catches yielding important numbers. In May the population became augmented in Massachusetts and Cape Cod Bays. In midsummer populations rivalling those on the offshore banks developed here and increased numbers were found all along the coast to the eastward by early autumn. These numbers did not maintain themselves, however, with the coming of winter.

The waters over the deep basin of the Gulf and over the Eastern Channel were always scantily populated. There was not much fluctuation in numbers with season in the northern and western parts of the basin. In the southeastern half, particularly in the region north of Georges Bank, there was a distinct increase in the numbers taken, beginning in July and developing clearly in September.

We propose the following considerations in explanation of the observed distribution of *S. elegans* in these different regions. Georges Bank is the seat of a great anticyclonic eddy (Huntsman, 1924; Bigelow, 1927). The dynamic contours in Fig. 6 indicate the magnitude of this eddy. Because of its size and attendant permanence, the population of sagitta remains on the Bank in sufficient numbers to maintain a dense breeding stock. Fluctuations in numbers are only such as are to be expected in an animal reproducing periodically. The decline in numbers at the close of the reproductive season is to be attributed to the natural death of the parental generation and the loss of small numbers to adjoining bodies of water. This situation represents the most favorable condition for maintaining an endemic population. Since, as Russell (1932) has shown, *S. elegans* produces several broods per year, since these are not exactly synchronized, and there is only a short period of

reproductive inactivity in the early winter, fluctuations in numbers are too small to be discerned readily.[6]

The water south of Cape Sable is not recognized as forming a definite eddy, but it is spoken of as a "dead area" subject to strong tidal influence, but for considerable periods relatively free of residual drift. The dynamic contours presented in Fig. 10 show that this condition persisted from April through September in 1934. The freedom from strong currents enables the progeny of this population to accumulate in great numbers during the breeding season. At the end of the period of multiplication the population becomes rapidly scattered, as evidenced by the increased numbers over the coastal banks and deeper waters in the northeastern quarter of the Gulf in the fall and winter.

The alteration of the coastal currents during the winter, discussed in connection with *S. serratodentata,* contributes to the disintegration of this center of abundance. Adjoining extensive breeding areas to the eastward, however, this region remains populated throughout the year. Although the physical and biological conditions south of Cape Sable may be as favorable as on Georges Bank, and the areas to the eastward assure a constant supply of fresh immigrants, the hydrographic set-up does not have sufficient stability to maintain a rich population during the winter.

The coastal waters off the northern shores of the Gulf are the seat of a strong flow to the westward. A non-tidal drift of 7 miles per day is recorded at Portland lightship. Though conditions may not be unsuitable for reproduction in this area, the yield is swept on to the west and south. As a result, only in the relatively immobile waters of Massachusetts Bay is there an opportunity for large numbers to be produced by breeding early in the summer, while the stock grows more slowly in the region to the eastward. With the termination of multiplication the population of the entire coastal zone is rapidly reduced as the waters are swept on, and the population is incorporated into that of Georges Bank and the deeper basin to the north of it.

It is hard to believe that the deeper waters of the Gulf are scantily

[6] *S. elegans* appears to breed in the Gulf of Maine in the late spring and summer. Individuals less than 10 mm. in length may be taken from May to September in Massachusetts Bay and on Georges Bank. Huntsman and Reid (1921) consider the spawning season in the Bay of Fundy to extend from April to September, though the eggs do not develop properly until late summer and the authors doubt if conditions for reproduction are sufficiently favorable in that locality to enable the species to perpetuate itself except by immigration. In the Woods Hole region Fish (1925) found ripe eggs as early as March and April. Russell (1932) has detected four or possibly five successive broods of *S. elegans* in the English Channel, the first appearing as ripe adults in January, the last in October.

populated either because food is lacking or because its physical conditions are unfavorable. Plankton in general is rich in the deep basin, and though perhaps not as plentiful as on the banks, it would surely support more than one-thousandth as many sagitta. The differences in temperature and salinity in the surface waters are trivial. We suggest that the water over the basin is free from *S. elegans* for the same reason that it is populated with *S. serratodentata.* The reciprocal character of the distribution of the two forms is evident both from our own and Huntsman's observations. The superficial water lying over the deep basin of the Gulf is renewed from external sources, in which *S. serratodentata* occurs, but *S. elegans* is lacking. The flow of this water is sufficiently rapid at all times so that *S. elegans* becomes incorporated into it only in small numbers, particularly in the region of inflow and along the northern half of the Gulf. By the time the southern side of the Gulf is reached in the course of the flow about the great eddy which fills the Gulf, *S. serratodentata* has died off, but *S. elegans* has had time to penetrate in larger numbers into the waters overlying the deep basins. This penetration can occur, however, only at those times when a rich population has grown up in the coastal waters, that is, after midsummer, and when this supply is exhausted in early winter the offshore waters become depopulated, both from the death of their inhabitants and their transport out to sea.

Discussion

We have attempted to analyze the distribution and abundance of chaetognaths in the Gulf of Maine on the basis of certain biological characteristics of the species and the movement of the water in which they live. We believe the character of their distribution within the area studied can be accounted for in the main in these terms without recourse to considerations of the suitability of the physical characteristics of the water for survival of the adults or of nutritive conditions.

The biological characteristics taken as given are the depth of water which the species frequents and the character of the water in which it succeeds in breeding. The former is doubtless controlled by choice, tropisms, or avoidance reactions on the part of the individual. Such reactions are left out of account as necessary factors in determining horizontal distribution, it being sufficient to consider that this is determined by the flow and mixing of the water masses in which the animals live. Active swimmers such as the chaetognaths might be capable of definite migrations such as many fish perform. There is no evidence that such directed movements influence the distribution of these forms, though Meek (1928) has claimed that cross-current migrations do influ-

ence the character of the sagitta population along the Northumbrian coast. In the absence of directed migrations, their swimming may be expected merely to accentuate the scattering of the population in horizontal directions at rates greater than the concurrent mixing processes in the water itself.

The situations in which a species can breed are, of course, controlled in some way by the physical characteristics of the water, particularly its temperature. Many species are able to survive as adults in regions in which reproduction is not possible. Five of the six chaetognaths considered fall into this category in the Gulf of Maine. Success in breeding is itself a relative matter and in " marginal " regions insufficient eggs may develop to maintain the local stock. *S. elegans* in the Bay of Fundy appears to be a case in point. There Huntsman and Reid (1921) find that the conditions are unfavorable for the development of larvae and conclude that the very considerable fluctuations in their numbers are caused by the adults being carried into the Bay in varying quantities. We may classify each species as it occurs in a given locality in an order of fecundity which decreases in its favorable effect on the maintenance of the population thus: (1) successful breeder; (2) unsuccessful breeder; (3) non-breeding immigrant.

These categories are merely relative. Success in breeding will affect the abundance of the population both in proportion to the number of eggs spawned and the fraction of these which survive.

Fluctuations in the stock present at any time will depend in part on the purely biological facts relating to the breeding habits. Animals having an annual period of reproduction will show a marked fluctuation with maximal numbers immediately following the period of breeding. The fluctuations will be most marked if the adult does not long survive its first breeding, less pronounced if the adult survives through several breeding seasons. Species which maintain their abundance by the production of many eggs with small expectancy of survival will fluctuate more than those less fecund species with low mortality. The degree to which the reproduction of different species is synchronized with the season will also modify the seasonal incidence. The life histories of the sagittae are not sufficiently well known to permit of classification in these regards. Fluctuations appear to be relatively small in *S. elegans* on Georges Bank, the most stable region of its occurrence. The deep-water species are free from marked fluctuation as is *S. serratodentata* according to Bigelow and Sears (1939) in its reproductive area south of Cape Cod. The marked fluctuations in the latter and the periodic occurrence of *S. enflata* appear to depend on environmental causes, rather than on the biology of the reproductive cycle.

A final biological factor determining both abundance and distribution is longevity. Within a region of production the relation of mortality to reproductive rate is obvious and has been mentioned above in considering fluctuations of biological origin. In the case of immigrant plankton, which are carried beyond the areas of successful breeding, the longevity of the individuals will determine the distance which may be travelled and the relative numbers to be found in regions increasingly remote from the centers of production. The deep-water chaetognaths afford examples of this sort as do *S. serratodentata* and *S. lyra.*

In nature these biological factors are at play in a scene determined by the given hydrography of various regions. The permanence of a maximal population demands that the breeding stock shall not be scattered by the flow of water, or that such losses shall be balanced by recruitment from other rich areas. The most favorable conditions for endemic existence will be found in large areas where suitable conditions are found and in which the water remains more or less permanently. Such an area is provided by the great eddy which appears to exist on Georges Bank and here *S. elegans* maintains a dense and stable population in spite of the fact that there is little opportunity of recruitment from other regions. Russell (1936*b*) considers the source of the water which occasionally carries *S. elegans* into the English Channel to be an area of cyclonic circulation lying south of Ireland.

When opportunities for recruitment by immigration from adjoining areas are good, rich populations may be developed in regions which do not develop permanent eddies in spite of a relatively rapid dissipation, as in the case of the banks south of Cape Sable. In such areas the seasonal fluctuations become greater and increasingly so in small areas such as Massachusetts Bay in which little time is required to wash away the dense populations, as soon as the period of multiplication is passed. In such regions the population is pseudo-endemic inasmuch as it is dependent on immigration to a high degree.

Bodies of water originating in regions where a species cannot maintain a production center may acquire a population by immigration from such centers in the course of its drift. The scanty populations of *S. elegans* which are found in the waters over the central basin of the Gulf of Maine appear to be of this type. Such populations become richer the longer the water is in proximity to the source area of production. Whether the species can reproduce in the area or not, it cannot achieve significant numbers because the water moves on too rapidly to permit an accumulation. Such populations may show seasonal fluctuations reflecting the reproduction periods of the areas from which they are derived, as in the southern half of the basin.

The origin of water bodies having distinctive physical characteristics results primarily from the mixing of other characteristic waters. The formation of slope water through the admixture of tropical, boreal and coastal waters is a case in point. In its synthesis the inhabitants of the contributing regions become incorporated into it and are carried with it to regions remote from their centers of reproduction. Such immigrants, if unable to reproduce themselves, can travel only so far as their life span will permit. They may be regarded as terminal immigrants in contrast to the forms such as *S. elegans* in Massachusetts Bay which form pseudo-endemic populations in regions continuously swept out by the passing waters. *E. hamata, S. maxima* and *S. lyra* are examples of this category.

Immigrants, both terminal and pseudoendemic, may show fluctuations both as the result of the reproductive cycle and for hydrographic causes. While the fluctuation of the pseudo-endemic population of *S. elegans* in Massachusetts Bay is probably due to seasonal reproduction in an area of relatively constant dissipation by currents, a changing current pattern may contribute largely to the fluctuation of the population of this species off Cape Sable. *Limacina retroversa* fluctuates greatly in numbers in the Gulf because it enters intermittently presumably because of fluctuations in the sources of the water entering the Gulf. Though it may be classed as an unsuccessful breeder in the Gulf, the important reason for its failure to develop a truly endemic population is the rapid flow of water across the surface of the basin which carries it away following its intermittent periods of invasion. *Limacina retroversa* is thus an unsuccessful pseudo-endemic form fluctuating for hydrographic reasons.

S. serratodentata, essentially a terminal immigrant in the Gulf of Maine, fluctuates in its occurrence for reasons which appear to be largely hydrographic. Being unable to survive long after the cessation of the inflow which introduces it into the Gulf, its fluctuations so far as this area is concerned are more marked than any others. *S. enflata,* occurring as a rare straggler along the borders of the Gulf, is the extreme case of terminal immigration. Its occurrence in late summer, along with many other tropical forms, suggests a definite movement of tropical water onto our shores at that time. The water in which these forms occur does not differ from normal coastal water in salinity. Their presence is due to the admixture of exceedingly small amounts of tropical water into that of the coastal banks. Their seasonal occurrence is to be related to the annual temperature cycle of the coastal waters. Unable to survive the chilling of winter, these rare stragglers are unable to travel far from their production areas beyond the slope water until the latter part of summer.

Among the chaetognaths, only one—*S. elegans*—has established a truly endemic existence in the Gulf of Maine, and this on the coastal and offshore banks. It alone achieves important numbers for this reason, and it alone is sufficiently numerous so that nutritive conditions may limit its numbers. The other species are immigrants from other regions and occur in numbers depending on the remoteness of their areas of production and no doubt on their abundance in such regions.

We may inquire why the basin of the Gulf has acquired no successful endemic population of chaetognaths. So far as the surface waters are concerned, the answer seems to be that these circulate so rapidly that time is not permitted for the accumulation of even a considerable pseudo-endemic population. The evidence is found in the history of *Limacina retroversa* and of *S. elegans* in the southern half of the basin. In the deeper water this difficulty can scarcely obtain. These waters derived from the slope water undergo rapid modification within the Gulf by admixture with surface water and acquire lower temperatures and salinities than those characterizing the slope water at comparable depths, and lower salinities than slope water of the same temperature. The process of creating a characteristic water mass, such as the slope water is, is continuing actively in the basin of the Gulf. Perhaps for this reason no chaetognath has yet appeared capable of reproducing successfully in this unique and limited region. However this may be, it is clear that the basin of the Gulf does support a rich endemic population of Crustacea. How this is possible should be the subject of future study.

Summary

1. Data are presented concerning the distribution and numerical abundance of five species of chaetognaths taken in the Gulf of Maine during the year 1933–34 and the hydrographic features controlling their abundance is discussed.

2. It is concluded that *Eukrohnia hamata, Sagitta maxima* and *S. lyra,* which are carried into the Gulf by deep currents and do not breed there, occur in numbers which depend not only on their relative abundance in various offshore waters which mingle in the Gulf, but on their longevity after entering the Gulf.

3. *Sagitta serratodentata* is a terminal immigrant from the superficial waters of the Atlantic which fluctuates in its abundance as the result of periodic changes in the circulation of water entering the Gulf from the east.

4. *Sagitta elegans* is the only chaetognath truly endemic to the region. The permanence of its occurrence appears to depend on the presence of

a relatively stable eddy on Georges Bank. Its occurrence in other regions varies with the season to a degree which may be explained by local conditions of circulation.

5. *Sagitta enflata* is recorded for the first time from the margins of the Gulf of Maine.

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Contribution No. 280

THE EFFECT OF OXYGEN TENSION ON THE RATE OF OXIDATION OF ORGANIC MATTER IN SEA WATER BY BACTERIA[1]

By

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It is generally recognized that the oxygen consuming capacity of heterotrophic bacteria in water serves as a good criterion of the amount of respirable or oxidizable organic matter in the water. However, the fragmentary literature on the subject records contradictory observations on the effect of oxygen tension upon the rate of bacterial oxidations. For example, Pomeroy (1938) found the amount of oxygen consumed by diluted sewage containing from 0.7 to 17.5 cc. of oxygen per liter to be independent of the oxygen tension but Heukelekian (1936) noted the maximum consumption of oxygen in such sewage mixtures containing around 10.5 cc. of oxygen per liter. According to Waksman and Carey (1935a) organic matter in sea water is oxidized more and more slowly as the oxygen tension is reduced. Conversely ZoBell and Stadler (1940a) report that the rate of bacterial oxidation of organic matter in lake water is not influenced by the oxygen tension within the examined ranges of 0.21 to 25.5 cc. of oxygen per liter.

In order to standardize procedures for the determination of the respirable organic matter content of sea water as well as to estimate the amount of oxygen being consumed by bacteria *in situ* it is necessary to have information on the effect of oxygen tension on bacterial respiration. The far-reaching significance of such determinations is emphasized by Sverdrup (1938) who points out that a rational explanation of the distribution of oxygen is the oceans awaits information on the "amount of oxygen-consuming organic matter" at different depths and the effect of oxygen content of the water on oxygen consumption.

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EXPERIMENTAL

Sea water was collected in 5-gallon carboys from Buzzards Bay or Vineyard Sound and brought into the laboratory. It was filtered through No. 25 bolting silk and thoroughly shaken to insure uniformity in its bacterial and chemical composition. The water was warmed to 22° C. and distributed in 4 l. quantities in gallon bottles. Tank nitrogen, or oxygen as required, was bubbled through the water until the dissolved oxygen of the water was adjusted to the desired concentration. By using flow meters it became possible to admit almost exactly the required amount of nitrogen or oxygen. The water was siphoned into 140 ml. glass-stoppered bottles under an atmosphere of nitrogen and oxygen which was in equilibrium with the partial gas pressure of the water being bottled. The oxygen content of the first two bottles filled with water and the last two was determined at once, these being used as controls to show the initial dissolved oxygen content of the water. The remaining bottles of water were placed in a water bath at 22° C. and the oxygen content determined after different periods of incubation.

The oxygen tension of the water was determined by the Winkler technique (Thompson and Robinson, 1939) using a microburette and N/100 sodium thiosulphate for titrations. In most cases the initial quadruplicate determinations agreed to within 0.03 cc./l. and the series was discarded if the divergence of duplicates exceeded 0.10 cc./l.

The bottles, siphons and other glassware used in the experiments were cleaned with sulphuric-acid dichromate solution and thoroughly rinsed. These precautions were exercised because of the known tendency of organic matter and bacteria to accumulate on glass immersed in water (Stark et al., 1938).

Adjusting the oxygen tension of sea water by the procedures outlined above has a slight effect on the carbon dioxide tension and may alter other properties of the water but the following experiment demonstrated that neither the rate nor the amount of oxygen-consumption was influenced by such treatment. Part of a sample of sea water was transferred to each of several glass-stoppered bottles without treatment. The oxygen tension of the second portion of the water sample was reduced to 0.64 cc./l. by bubbling nitrogen through it. Part of this was then bottled and to the remainder oxygen was admitted until it approximated the oxygen content of the original sample. Oxygen was bubbled through another portion of the water sample until it contained 12.74 cc./l. Part of this was bottled and to the remainder nitrogen was admitted until the oxygen tension was reduced to approximately that of the original sample after which it was bottled. Duplicate

bottles of water receiving each treatment were analyzed after different periods of incubation in the water bath at 22° C. The results which are summarized in Table I show that within the limits of experimental error the same amount of oxygen is consumed by the respiring bacteria in sea water regardless of the treatment of the samples with nitrogen or oxygen.

The effect of oxygen tension on the rate of bacterial respiration in sea water was studied by adjusting the oxygen tension of different lots of a large sample of water collected from Buzzards Bay (6/23/39) at concentrations ranging from 0.41 to 18.04 cc./l. by treating with either

TABLE I

OXYGEN CONSUMED AFTER DIFFERENT PERIODS OF TIME AT 22° C. BY BACTERIA IN SEA WATER THE GAS TENSION OF WHICH HAD BEEN ALTERED BY BUBBLING EITHER NITROGEN OR OXYGEN OR BOTH GASES ALTERNATELY THROUGH THE WATER

Gaseous treatment	*Initial dissolved oxygen*	*Oxygen consumed after*			
		2 days	*5 days*	*10 days*	*20 days*
	cc./l.	cc./l.	cc./l.	cc./l.	cc./l.
None	5.46	0.24	0.39	0.87	1.26
Nitrogen	0.64	0.25	0.34	0.62	—
Nitrogen + oxygen	5.72	0.28	0.43	0.95	1.21
Oxygen	12.74	0.21	0.41	0.97	1.32
Oxygen + nitrogen	5.30	0.25	0.36	0.84	1.24

nitrogen or oxygen. Quadruplicates were analyzed for oxygen content at once and duplicates after different periods of incubation in the water bath at 22° C. Prior to the addition of the Winkler reagents 1.0 cc. of water from each bottle was withdrawn for estimating the bacterial populations. Appropriate dilutions were plated with nutrient sea water agar and the colonies were counted after 10 days incubation at room temperature. From these data the amount of oxygen consumed per bacterial cell was calculated by applying the formula of Buchanan and Fulmer (1930): $m = \frac{2.303\, S \log b/B}{t(b - B)}$, where m is the amount of oxygen consumed per cell per hour, S the total amount of oxygen consumed in time t, B the number of bacteria at the beginning of the experiment and b the number after time t. Table II records the amount of oxygen which was consumed by the bacteria after different periods of incubation in water containing different concentrations of oxygen and the amount of oxygen which was consumed per cell per hour during the first two days of the experiment. Although all of the requisite conditions do not prevail to make the application of the

formula of Buchanan and Fulmer strictly valid, it is noteworthy that for each oxygen tension the rate of respiration of the bacteria is found to be of the same order of magnitude.

The rate of oxygen consumption was virtually the same for water of all oxygen concentrations until the concentration of oxygen was reduced to less than 0.2 cc./l. The rate of oxygen consumption decreased after two days incubation at 22° C. Excluding the first two series in Table II which initially contained the least dissolved oxygen and in which the

TABLE II

OXYGEN CONSUMED BY MULTIPLYING BACTERIA IN SEA WATER CONTAINING DIFFERENT CONCENTRATIONS OF DISSOLVED OXYGEN AT 22° C. AND THE AMOUNT OF OXYGEN CONSUMED PER CELL PER HOUR DURING THE FIRST TWO DAYS OF THE EXPERIMENT AS CALCULATED FROM DATA ON THE BACTERIAL POPULATIONS AND THE OXYGEN TENSION

Initial dissolved oxygen	*Oxygen consumed after* 1 day	2 days	5 days	10 days	*Oxygen consumed per cell per hour during first two days*
cc./l.	cc./l.	cc./l.	cc./l.	cc./l.	cc.
0.41	0.07	0.20	0.37	0.39	13.9×10^{-12}
0.77	0.06	0.24	0.55	0.72	9.2×10^{-12}
1.19	0.06	0.21	0.62	0.95	12.5×10^{-12}
2.36	0.08	0.26	0.56	0.91	16.1×10^{-12}
5.10	0.07	0.28	0.59	0.98	15.0×10^{-12}
8.26	0.09	0.25	0.61	0.92	14.3×10^{-12}
12.74	0.05	0.23	0.67	0.91	16.4×10^{-12}

total oxygen consumption was limited after two to five days by the amount of oxygen present, the bacteria consumed an average of 14.9×10^{-12} cc. of oxygen per cell per hour during the first two days of the experiment. The average rate had dropped to 9.5×10^{-12} cc. per cell per hour for five days and to 4.7×10^{-12} cc. for ten days. In fact, from the fifth to the tenth day of the experiment the bacteria were consuming an average of only 2.6×10^{-12} cc. of oxygen per cell per hour. The decreasing respiratory rate is attributed to the progressive utilization of the more readily oxidizable fractions of organic matter occurring in the sea water, although it may also be influenced by the age of the cells. It has been shown by Clifton and Logan (1939) and others that young cells in the logarithmic phase of growth use more oxygen than older cells. The tendency of the bacteria to adhere tenaciously to the glass walls of the bottle causing many respiring bacteria to escape detection by plating procedures is another complicating factor (ZoBell, 1936). For this reason the rate of respiration

after several days incubation may be considerably less than 2.6×10^{-12} cc. per cell per hour as estimated because there are probably as many or even more respiring bacteria which are tenaciously attached to the walls of the glass bottles than the number which are detected in the water by the conventional plate count procedure.

The enrichment of sea water with readily oxidizable substances accelerates the rate of oxygen consumption by bacteria. As has been shown by Waksman and Carey (1935b) the addition of utilizable organic matter to sea water causes a large increase in the bacterial population and oxygen consumption. According to Johnson (1936) the enrichment of sea water with 0.04 per cent of glucose increased the rate of respiration of marine bacteria 10 to 378 per cent. Similar results have been reported by ZoBell (1940) for both "resting" cells and multiplying cultures from lake water. In order to ascertain if the effect of oxygen tension on the rate of oxidation of organic matter is more pronounced in the presence of larger concentrations of readily utilizable organic matter, sea water was enriched with 0.05 per cent each of glucose and asparagine. The water was inoculated with mixed cultures of marine bacteria to give an initial bacterial population of approximately two million viable cells per cc. and the oxygen tension of different lots of the water was adjusted to range from 0.48 to 7.43 cc./l. The oxygen content of the water was determined from hour to hour and the amount of oxygen consumed was calculated. The results which are summarized in Table III show that the oxygen tension has

TABLE III

EFFECT OF OXYGEN TENSION ON THE OXYGEN UPTAKE OF BACTERIA IN SEA WATER ENRICHED WITH 0.05 PER CENT EACH OF GLUCOSE AND ASPARAGINE

Initial dissolved oxygen	*Oxygen consumed after* 2 hours	4 hours	6 hours	10 hours	16 hours
cc./l.	cc./l.	cc./l.	cc./l.	cc./l.	cc./l.
0.48	0.05	0.15	0.31	0.48	0.48
1.14	0.06	0.14	0.34	0.91	1.14
1.97	0.07	0.18	0.38	1.01	1.46
4.15	0.04	0.12	0.35	0.95	1.53
7.43	0.03	0.17	0.40	1.04	1.61

no influence on the rate of respiration of bacteria in sea water enriched with organic matter until the oxygen tension is reduced to a very low level.

Waksman and Renn (1936) suggest that the effect of oxygen tension may be more pronounced when refractory substrates are being oxidized.

Therefore the experiment was repeated using aged sea water enriched with 0.05 per cent of ferric lignoprotein, a compound which is not readily oxidized by bacteria. The lignoprotein was obtained from Dr. Waksman. The "aged" sea water had been stored in the laboratory for several weeks to permit bacterial activity to oxidize the respirable organic matter. Controls run with this water revealed that it consumed only 0.26 cc. of oxygen per liter in 20 days at 22° C. The lignoprotein was slowly oxidized by the bacteria as indicated by bacterial multiplication and oxygen consumption but the rate of oxidation was found to be independent of the oxygen tension within the examined range of 0.41 to 8.93 cc. of oxygen per liter. The results of the experiment which has been repeated with similar findings are presented in Table IV.

TABLE IV

EFFECT OF OXYGEN TENSION ON THE OXYGEN UPTAKE OF BACTERIA INCUBATED AT 22° C. IN AGED SEA WATER ENRICHED WITH 0.05 PER CENT OF FERRIC LIGNOPROTEIN

Initial dissolved oxygen	*Oxygen consumed after* 1 day	2 days	3 days	5 days	10 days
cc./l.	cc./l.	cc./l.	cc./l.	cc./l.	cc./l.
0.42	0.30	0.41	—	—	—
0.99	0.37	0.61	0.82	0.92	—
2.00	0.39	0.70	0.87	1.21	1.54
4.76	0.37	0.58	0.80	1.04	1.53
8.93	0.34	0.59	0.76	0.96	1.34

The lignoprotein was oxidized much more slowly than glucose or asparagine. A sample of isolated lignin purified by Bartlett and Norman (1938) was also found to be slowly oxidized by bacteria in sea water. From water enriched with 0.05 per cent of the lignin and which initially contained 0.78, 2.19, 5.30 and 9.04 cc. of oxygen per liter there was consumed an average of 0.54, 0.65, 0.57 and 0.61 cc. of oxygen respectively in 58 days at 22° C. ZoBell and Stadler (1940b) found that each of eleven different samples of purified or isolated lignins was slowly oxidized by bacteria in lake water and the rate of oxidation was independent of the oxygen tension until the latter was reduced to less than 0.3 cc. of oxygen per liter.

Waksman and Renn (1936) showed that the filtration of sea water removes an appreciable quantity of the oxygen consuming constituents and in so doing the effect of oxygen tension on the rate of oxygen consumption is amplified. The former observation has been confirmed by testing the oxygen consuming capacity of sea water treated in different

ways. Large samples of surface water were divided into three lots. The first was siphoned into glass-stoppered bottles without any treatment. The second lot was filtered through No. 25 bolting silk and then bottled. The third lot was filtered through a No. 4 sintered-glass filter and shaken to equilibrate it with air after which it was bottled. An unfiltered sample of surface water collected from Buzzards Bay (6/24/39) was found to consume 0.86 cc. of oxygen per liter in 20 days at 22° C. That which was filtered through bolting silk consumed 0.60 cc. of oxygen per liter while the sintered-glass filtered water consumed only 0.49 cc. of oxygen per liter. Unfiltered, silk-filtered and sintered-glass filtered water collected from Vineyard Sound (8/4/39) consumed 1.09, 0.75 and 0.53 cc. of oxygen per liter respectively in 20 days at 22° C.

Using the method suggested by Dr. C. E. Renn a large volume of sintered-glass filtered sea water was obtained by immersing 2-liter bottles fitted with No. 4 sintered-glass filters to a depth of ten or twelve fathoms where the hydrostatic pressure forced water into the bottles. This water from which much of the particulate and readily utilizable organic matter had been removed by the filters was tested for its oxygen consuming capacity in the presence of different concentration of dissolved oxygen. The oxygen tension of aliquot parts of the water was adjusted at different levels ranging from 0.49 to 9.05 cc./l. and the amount of oxygen consumed after different periods of incubation at 22° C. was determined. Corroborating previous findings it was found that the rate of oxygen consumption was appreciably slower in the sintered-glass filtered water than in unfiltered water collected from the same station and secondly, it was found that regardless of the more refractory characteristic and smaller concentration of the organic matter in the sintered-glass filtered water, the rate of oxidation

TABLE V

Effect of Oxygen Tension on the Oxygen Uptake of Bacteria in Sea Water Incubated at 22° C. Which Had Been Filtered *in situ* Through a No. 4 Sintered-Glass Filter

Initial dissolved oxygen	*Oxygen consumed after* 2 days	5 days	10 days	20 days
cc./l.	cc./l.	cc./l.	cc./l.	cc./l.
0.49	0.09	0.28	0.37	0.46
0.94	0.12	0.25	0.45	0.61
1.87	0.08	0.32	0.51	0.59
3.70	0.08	0.29	0.46	0.64
5.24	0.10	0.28	0.52	0.70
9.05	0.11	0.30	0.49	0.58

of the organic matter was independent of the oxygen tension over a wide range. The results are summarized in Table V.

In the foregoing experiments it was noted that the rate at which bacteria oxidize organic matter is not influenced by the oxygen tension of sea water until the latter is reduced to 0.2 to 0.3 cc. of oxygen per liter (see Tables II and V). Below this concentration of dissolved oxygen the rate of oxygen consumption decreases with decreasing oxygen tension. However, when corrections were made for the minute amounts of oxygen introduced by the Winkler reagents it was found that respiring bacteria are able to remove the last detectable trace of oxygen from sea water provided other conditions including utilizable organic matter do not become limiting factors.

DISCUSSION

The rate of oxidation of organic matter by bacteria in sea water does not seem to be influenced by the concentration of oxygen within the examined range of 0.3 to 12.74 cc./l. although it is influenced by the concentration of oxidizable organic matter. Apparently dissolved oxygen in sea water becomes a limiting factor in the bacterial oxidation of organic matter only when the concentration of oxygen is reduced to less than 0.3 cc. per liter. However, oxygen might become a limiting factor in localized microspheres rich in oxidizable matter such as, for example, the bodies of decomposing plankton organisms, if oxygen is consumed more rapidly than it can be replaced by diffusion from the surrounding water. Under these conditions a high oxygen tension in the surrounding water might be beneficial because it would increase the oxygen gradient and hence expedite the diffusion of oxygen to the oxygen-deficient microsphere.

According to Rashevsky (1933) the rate of oxygen consumption by protoplasm is independent of the oxygen tension except in so far as the latter might influence the diffusion or penetration rate of oxygen. Similarly Shoup (1929) concludes that "a constant and maximum rate of oxygen consumption occurs in small cells when the oxygen concentration becomes sufficient to entirely saturate the surface of the oxidative catalyst of the cell." He found that light production by photogenic bacteria, an oxidative reaction, was not dimmed until the oxygen was reduced to less than 0.1 cc. per liter.

Although most workers (Amberson, 1928, Harvey, 1928, Hyman, 1929, Shapiro, 1934, ZoBell and Stadler, 1940a) find that the respiratory rate of aquatic unicellular organisms is independent of oxygen tension over a wide range, there seem to be certain exceptions. Different bacteria may have different types of respiratory metabolism as

indicated by Schlayer's (1936) observation that 20 to 30 per cent of oxygen is optimum for the respiration of *Pneumococci* while the respiration of certain other bacteria he studied is unaffected by the concentration of oxygen until the latter is reduced to less than one per cent (about 0.2 cc. per liter). The difference may be related to the membrane permeability of the bacteria or it might be related to the e.m.f. or other peculiarities of the biological system. It is noteworthy that certain bacteria whose respiration is reported to be favored by a high concentration of oxygen, namely, *Pneumococci* (Schlayer, 1936), *Azotobacter* (Burk, 1930) and *Rhizobia* (Georgi and Wilson, 1933), are surrounded by capsular membranes which might tend to retard the diffusion of oxygen. Taylor (1935) has shown that there is a relationship between the respiratory rate and the e.m.f. of certain cells, and the e.m.f. in turn is influenced by the oxygen tension. Kempner (1937) reports that at low temperatures or with old cells the respiration of *Escherichia coli* is independent of the oxygen tension, but near the optimum temperature or with young cells the rate of respiration is a function of the oxygen tension.

The observations reported above as well as the work of Waksman and associates show that the concentration as well as the quality of the organic matter influences the rate at which it is oxidized. In general, the rate of bacterial respiration increases as the concentration of oxidizable organic matter increases but additional experiments must ascertain the range within which this generalization maintains. Working with lake bacteria ZoBell (1940) found that the optimum concentration of glucose for the respiration of lake bacteria was between 100 and 1000 mgm./l. and similar results were obtained with glycerol, asparagine and lactic acid. With this concentration of organic matter the rate of bacterial respiration independent of the favorable influence on bacterial multiplication was appreciably faster than in the presence of only 5 to 10 mgm. of organic matter per liter, the concentration which occurs in sea water. Considering that most of the organic content of sea water is highly refractory to bacterial oxidation, it appears that the concentration of organic matter is near the threshold of the requirements for bacteria which probably accounts for the paucity of bacteria in the ocean. There is no direct evidence that a lack of either utilizable nitrogen or phosphorus limits bacterial activity in the ocean although it has been demonstrated by Waksman and Carey (1935b) and Waksman and Renn (1936) that nitrogen limits bacterial activity when glucose is added to sea water.

Whereas the bacteria in sea water incubated at 22° C. consumed only 14.9×10^{-12} cc. of oxygen per cell per hour, they consumed

nearly four times as much or 54.1×10^{-12} cc. of oxygen per cell per hour at this temperature when the sea water was enriched with 0.05 per cent each of asparagine and glucose. Considering that the bacteria approximate spheres having a mean diameter of 1.0 μ and a density near that of sea water, it is estimated that in the sea they use about 30 cc. of oxygen per hour per gram of living cells and nearly four times as much (around 110 cc. per hour per gram) in the presence of an abundance of oxidizable organic matter. Heilbrunn (1937) has compiled data which show that various marine animals consume only from 0.002 to around 1.0 cc. of oxygen per hour per gram of fresh living material under comparable conditions. However, in spite of the relatively large oxygen consuming capacity of respiring bacteria, it would require a bacterial population of more than seven thousand per cc. to consume 1.00 cc. of oxygen from a liter of sea water in a year at 22° C., and proportionately more at lower temperatures. According to Johnson (1936) the Q_{10} of marine bacteria is 2.3 between 5° and 15° C. and 2.18 between 15° and 25° C.

If the results of this paper are applicable to conditions in the ocean, they have an important bearing on the explanation of the distribution of dissolved oxygen. It follows that where the concentration of oxygen is more than 0.3 cc./l. there exists no relation between the amount of oxygen consumed by bacteria and the amount present. Assuming that the bacterial oxidation of organic matter is the principal cause of oxygen consumption at depths well below the photosynthetic zone, say below 300 meters, no conclusions can be drawn concerning the rate of oxygen consumption from observations on the amount of oxygen present or vice versa because the two quantities are independent of each other. This is contrary to Sverdrup's (1938) suggested explanation of the oxygen minimum in the ocean. However, in fairness it should be added that Sverdrup emphasized the speculative character of his suggestion which was made to arouse interest in the problem. Moreover, at that time upon being consulted the author expressed the opinion that judging from reports in the literature, oxygen consumption by marine bacteria might be directly proportional to the oxygen tension, an opinion which is contradicted by the present findings.

Going a step further it appears that the distribution of oxygen in the ocean cannot be explained by considering only processes *in situ* but it is also necessary as Seiwell (1937) has done to consider the "history" of the water masses. In order to do so properly the factors which influence oxygen consumption must be studied further.

SUMMARY

The rate of oxidation of organic matter in sea water as indicated by oxygen consumption by bacteria is independent of the oxygen tension within the examined range of 0.31 to 12.74 cc. of oxygen per liter.

As the concentration of oxygen is reduced below 0.3 cc. per liter the respiratory rate decreases, although if oxidizable organic matter is present bacteria can remove the last detectable trace of dissolved oxygen from sea water.

During the first two days of incubation at 22° C. bacteria in sea water were found to consume an average of 14.9×10^{-12} cc. of oxygen per cell per hour; progressively less thereafter as the more readily oxidizable fractions of organic matter were utilized.

Although the enrichment of sea water with 0.05 per cent each of glucose and asparagine accelerates the rate of respiration, the rate in the enriched sea water is not influenced by the oxygen tension within the stated limits.

Filtering sea water through silk plankton netting or sintered-glass removes much of the more readily oxidizable matter from sea water but the rate of oxygen consumption by bacteria in the filtered water is independent of the oxygen tension.

Lignoprotein as well as a sample of purified lignin was found to be slowly oxidized by marine bacteria, the rate being independent of the oxygen tension.

The probable rôle of bacteria in influencing the distribution of dissolved oxygen in the sea is discussed.

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Some Deep Sea Fishes from the North Atlantic[1]

By WILLIAM C. SCHROEDER

DURING the summers of 1937, 1938 and 1939, a few Blake-trawl hauls were made on bottom, in 640–2030 fathoms, by the research vessel "Atlantis" of the Woods Hole Oceanographic Institution, off the southern slope of Georges Bank during the course of submarine geology investigations. Mr. William E. Schevill was in charge of these hauls. Certain of the fishes proved to be comparatively rare or unknown in the western North Atlantic. All the fish caught, together with a few taken by "Atlantis" in 1936, and one specimen received from a fishing boat that same year, are included herewith.

LIST OF SPECIES

ALEPOCEPHALIDAE

Alepocephalus agassizii Goode and Bean, 1883

Alepocephalus agassizii Goode and Bean, Bull. Mus. Comp. Zool., 10, 1883: 218.

Depth 4.5 to 4.8; head 2.7 to 3.1; eye (horizontal) 3.6 to 4.2; snout 4 to 4.2; interorbital (bone) 6.5 to 7.8; D. 15 or 16; A. 15 to 17; V. 6 or 7; P. 12; scales 95 to 110. A single row of small, rather close set, curved teeth on the palatines, premaxillary and mandible. The maxillary, vomer and tongue are toothless.

Koefoed (1932: 36) gives an account, with detailed measurements, of five specimens taken in the eastern North Atlantic. For these the dorsal rays are given as 16–17, anal 17–18, pectoral 10–12 and scales about 80–90. The scale counts (95–110) on the "Atlantis" specimens were made from the upper angle of the voluminous gill cover to the base of the caudal. Nearly all of the other proportions given by Koefoed were in close agreement with the "Atlantis" specimens. The type of this species is in the collection of the M.C.Z. but is badly mutilated. Dr. Leonard Schultz kindly sent me an "Albatross" specimen from the U. S. National Museum collection for comparison. Color black.

Three specimens, 338, 473 and 642 mm. in total length were taken by "Atlantis" in three hauls made within a few miles of Lat. 40° 04′ N., Long. 68° 05′ W., in 1100–1250 fathoms, with a Blake-trawl fishing on bottom. These fish were brought up in very good condition.

Caribbean Sea; North Atlantic Ocean, on the western side from Lat. 36° 30′ N., Long. 74° 33′ W., to Lat. 41° 53′ N., Long. 65° 35′ W.; on the eastern side, off the southwest coast of Iceland and west of Great Britain near Long 12° W. in a depth range of 523–1250 fathoms.

STOMIATIDAE

Stomias boa ferox Reinhardt, 1842

A specimen 303 mm. long, to caudal base, was taken by a fishing trawler in Lat. 42° 10′ N., Long. 67° 05′ W., in about 100 fathoms, January 20,

[1] Contribution No. 283 from the Woods Hole Oceanographic Institution.

1936. Possibly it came from the stomach of another fish. Two specimens, 120–188 mm. in total length, were taken by "Atlantis" in Lat. 40° 01′ N., Long. 68° 06′ W., in a Blake-trawl which fished bottom in 1230 fathoms, July 27, 1939.

This species has been recorded, according to Ege (1934: 20), in the North Atlantic from Lat. 28° 15′ N. to southeastern Greenland and southern Iceland. Captures have been made at all levels from near the surface to at least 1000 fathoms.

MELANOSTOMIATIDAE

Chirostomias pliopterus Regan and Trewavas, 1930

One specimen, 93 mm. in total length, was taken in Lat. 35° 31′ N., Long. 69° 15′ W., in a 2-meter ring-net fishing 0–850 meters September 5, 1936. This specimen agrees well with the description of Regan and Trewavas (1930: 54) and with their figure on Plate I.

Atlantic Ocean north of 20° N. in a depth range of 55–700 fathoms.

CHAULIODONTIDAE

Chauliodus sloanei Schneider, 1801

One specimen, 82 mm., from Lat. 40° 05′ N., Long. 67° 52′ W., Blake-trawl fishing bottom in 1325 fathoms, July 25, 1939; one 112 mm. from Lat. 39° 50′ N., Long. 66° 50′ W., Blake-trawl fishing bottom in 2030 fathoms; one 250 mm. from Lat. 38° 25′ N., Long. 71° 04′ W., Sept. 2, 1935, 2-meter ring net, 0–360 fathoms.

Western Atlantic northward to the offing of New England; circumtropical; probably most plentiful in the upper 500 fathoms.

GONOSTOMATIDAE

Gonostoma bathyphilum (Vaillant), 1884

Two specimens, 150–154 mm. long to base of caudal, were taken in Lat. 39° 09′ N., Long. 68° 05′ W., in a Blake-trawl which fished bottom in 1280 fathoms, July 27, 1939.

North and South Atlantic. Beebe (1937: 201) records captures in hauls at 700–1000 fathoms, and Parr (1937: 41) with 8000–10000 feet of wire. Recorded down to 1430 fathoms.

Gonostoma elongatum Günther, 1878

A fish 191 mm. long was taken in Lat. 39° 18′ N., Long. 70° 32′ W. in a 2-meter ring-net haul of 0–400 meters, July 16, 1938.

Known from the North and South Atlantic Oceans, Indian Ocean and Hawaiian Islands. Deepest catch 2369 fathoms.

SERRIVOMERIDAE

Serrivomer beanii Gill and Ryder, 1883

One fish, 390 mm. long, was taken in Lat. 39° 40′ N., Long. 71° 43′ W. in a Blake-trawl fishing 820 fathoms, August 11, 1937, and another, of 605 mm. in about Lat. 39° N., Long. 70° W. on September 3, 1936, in a 2-meter ring-net hauled in 0–800 meters.

North Atlantic Ocean between 50 and 1000 fathoms and down to 3281 fathoms (Beebe and Crane, 1936: 54).

EURYPHARYNGIDAE

Eurypharynx pelecanoides Vaillant, 1882

One specimen, 430 mm. long, was taken in Lat. 40° 01′ N., Long. 68° 06′ W., in a Blake-trawl fishing bottom in 1230 fathoms, July 27, 1939.

Atlantic Ocean; on our coast northward to the offing of Nova Scotia. Bathypelagic.

SYNODONTIDAE

Bathysaurus ferox Günther, 1878

One specimen, 605 mm. long, was taken in Lat. 40° 01′ N., Long. 68° 06′ W., July 27, 1939, in a Blake-trawl which fished bottom in 1230 fathoms.

Recorded from the western Atlantic in Lat. 38° to 40° N., Long. 68° to 72° W.; eastern Atlantic from Lat. 27° to 50° N., Long. 8° to 33° W.; New Zealand. Depth range 647–1730 fathoms.

MYCTOPHIDAE

Myctophum affine (Lütken), 1892

One specimen, 89 mm. long, was taken in Lat. 34° 04′ N., Long. 65° 56′ W. with a surface light at night, June 23, 1938, and one 38 mm. was brought up in Lat. 40° 04′ N., Long. 68° 05′ W., in a Blake-trawl which fished bottom in 1250 fathoms, July 26, 1939.

Atlantic, Pacific and Indian Oceans.

Myctophum hygomi (Lütken), 1892

One fish was taken in Lat. 40° 04′ N., Long. 68° 05′ W., and another a few miles away in Blake-trawl hauls made in 1230–1250 fathoms, July 26–27, 1939. Length 50–63 mm.

Atlantic Ocean, Mediterranean Sea, Indian Ocean.

MACRURIDAE

Nematonurus armatus (Hector), 1875

Macrurus armatus Hector, Ann. Mag. Nat. Hist., (4) 15, 1875: 81.
Coryphaenoides gigas Vaillant, Possions Exped. Scient. du Travailleur et du Talisman, 1888: 232, pl. XX, fig. 2.

Depth 7; head 5.5; eye 4.3; snout 3.9; maxillary 2.7; interorbital 3.9; D. II-8, 90; A. 92; P. 20; V. 10. Scales about 150. The body is elongate, and much compressed posterior to first dorsal from which it tapers to the almost filamentous tip of the tail. The upper profile rises slightly from the interorbital to the first dorsal, posterior to which it continues almost straight. The lower profile, from the ventrals to the end of the tail, converges evenly with the upper. The scales are not very deciduous, have strong spines and are present everywhere on the body and top and sides of head. On many of the head scales the spines are radial, mostly in 7 to 9 rows while on most of the body scales they are parallel, chiefly in from 3 to 7 rows. The median row is somewhat the stronger on most of the scales and the spines in several or all of the rows extend beyond the margin. The lateral line rises gently anteriorly and ends a little short of and slightly above the upper angle of the operculum. The chin barbel in length is about two-thirds the horizontal diameter of the eye. There are numerous pores around the upper and the lower jaws.

The snout, which is somewhat damaged in the single specimen at hand, is rather blunt and extends a little beyond the mouth. A small knob at the tip is encrusted with small spiny scales. The eye, which nearly equals the interorbital width, is situated high, and enters the anterior profile. The interorbital is flat. The nostrils are situated immediately in front of the eye, the posterior pair being the larger. Branchiostegals 6. The mouth is situated on the lower side of the head, is nearly horizontal and of moderate size. The protractile upper jaw extends slightly beyond the lower. The maxillary goes 2.7 in the head and reaches the posterior one third of the eye.

The teeth, the same in both jaws, are relatively large (compared with the teeth of other species in this family) rather widely spaced, movable, and both upper and lower are in a single row. No vomerine or palatine teeth. The gill rakers are very short and there are 7 on the free portion of the lower limb of the first arch, part of which is attached by a membrane to the outer wall of the gill cavity.

The first dorsal originates less than an eye's diameter posterior to the origin of the pectoral. The first spine is very short while the second goes 1.44 times in the head and is rather strongly serrated, with 5 closely spaced spines near the base followed by about 10 spines which decrease in size and become more widely spaced toward the tip. The distance between the dorsals is equal to two-thirds the length of the head.

The second dorsal originates over the seventh anal ray. The sixth ray equals nearly one-half the diameter of the eye and the rays continue about the same length to the end of the tail, a small piece of which is missing in the specimen at hand.

The anal originates immediately behind the anus. The sixth ray somewhat exceeds the diameter of the eye and, like the dorsal, the rays continue about the same length to the end of the tail. The pectoral originates over the ventral fin, its outer margin is rounded, the upper rays are longest and go 1.7 in the head. The first ray of the ventral is filamentous and goes 2.2 in the head; the second ray 3.2. Color blackish.

One specimen, 340 mm. long, was taken in Lat. 39° 50′ N., Long. 66° 50′ W., in a Blake-trawl fishing 2025 fathoms, July 24, 1939.

Koefoed (1932: 109) gives a detailed account of this species in the eastern Atlantic and points out that there appears to be a considerable difference in the spination of the scales and of the serrated dorsal ray, according to age, and possibly habitat.

The "Atlantis" specimen is the first to be recorded from the western part of the North Atlantic. Previous records have been from the vicinity of the Azores, Bay of Biscay, Pacific Ocean, and New Zealand, in depths ranging from 406 to 2611 fathoms.

Chalinura simula Goode and Bean, 1883

Chalinura simula Goode and Bean, Bull. Mus. Comp. Zool., 10, 1883: 199. This species is described in detail by Goode and Bean (1896: 412) and by Koefoed (1932: 100).

Depth 6.8; head 4.9; eye 6; snout 3.5; maxillary 2.2; interorbital 4.3; D II–8, 120; anal about 120; P. 19; V. 9. Scales about 155. In the "Atlantis" specimen the pectoral goes 1.7, and the ventral fin, without fila-

ment, 3.2 in the head. The filament of the ventral is 1.3 times the length of the head and reaches the 10th anal ray. The pectoral originates about over the ventral and nearly an eye's diameter in advance of the dorsal. The scales are deciduous, not one remaining on the specimen at hand, and there are about 80 rows counting backward two head lengths from the upper angle of the opercle. Gill rakers short, 9 on the lower limb of the first arch.

The teeth in the upper jaw are in a rather wide villiform band, outside of which there is a single row of large teeth (40 counted) which curve inward at the tip. The teeth in the lower jaw are in a single row, straight, smaller than the large upper teeth and slightly more crowded.

The first dorsal spine is very short; the second (broken) is serrated, the spinules being close together and appressed to the spiny ray.

The one specimen in the M.C.Z. collection, 465 mm. long, has this same arrangement of spinules on the serrated dorsal ray. The tail is regenerated whereas in the "Atlantis" fish it is intact and continues almost to a filament.

One specimen, 440 mm. long, was taken in Lat. 39° 50′ N., Long. 66° 50′ W. in a Blake-trawl fishing 2025 fathoms, July 24, 1939.

Known from the coast of North America from Lat. 31° to 41° N. and from Long. 65° to 78° W., and from Denmark Strait, in depths ranging from 333 to 2025 fathoms.

Coryphaenoides bairdi (Goode and Bean), 1877

Macrourus bairdi Goode and Bean, Amer. Journ. Sci. Arts., 13, 1877: 471.

This common species may be recognized from other macrurids here described by its large eye which goes about 3 in length of the head [2.6 (fish 150 mm.) to 3.1 (fish 310 mm.)], by having usually II, 11 rays in the first dorsal and by its rather nondeciduous (compared with other species) scales, the exposed part of which is covered with small spinules, mostly in about 15 to 20 rows.

This grenadier is one of the most abundant fish on our continental slope below 100 fathoms (Bigelow and Welsh, 1925: 468). Occasionally it is taken in shoaler water (Bigelow and Schroeder, 1936: 340) and has been recorded as deep as 1255 fathoms. "Atlantis" trawled 18 specimens 150 to 400 mm. long, August 11, 1937, in Lat. 39° 28′ N., Long. 71° 58′ W. in 640 fathoms.

Known from along the continental slope from the Grand Banks of Newfoundland to the West Indies.

Coryphaenoides carapinus Goode and Bean, 1883

Coryphaenoides carapinus Goode and Bean, Bull. Mus. Comp. Zool., 10 (5), 1883: 197.
Macrurus carapinus Koefoed, Rept. "Michael Sars" North Atlantic Exped. 1910. Bergen Mus., 4, pt. 1, 1927 (1932): 107.

Eye 5 to 5.6; snout 2.8 to 3; maxillary 2.7 to 3; interorbital 2.7 to 3.1; D. II, 8; P. 18 or 19; V. 9 to 11.

The pectoral goes 1.5 to 1.8 and the ventral, without filament, 2.2 to 2.6 in the head, the filament reaching beyond the anus. The pectoral originates slightly in advance of the dorsal which is about over the ventral. In the specimens at hand the position of these fins, with respect to each other, agrees with the type.

The scales are deciduous but fortunately a few remain on the "Atlantis" fish and these were as follows: near the origin of the pectoral fin the scales were thin and without armature. A short distance posteriorly, along the side, the few scales found were faintly armed with a single small spinule in 3 or 4 rows. Along the side, opposite a space between the dorsals, the one scale found was conspicuously armed with 9 rows of spines which diverge outward very slightly and do not extend beyond the margin of the scale. Farther back along the side, under the origin of the second dorsal, and also a little posterior to this, a small patch of scales had 8 to 10 slightly diverging rows of spines, some of which extended beyond the scale margin. Accordingly, the scales on this species appear to be unarmed anteriorly and probably near the bases of the fins, and armed posteriorly, especially along the sides. This accounts for the two smooth scales found by Goode and Bean (1883: 197) at the base of the dorsal, the only scales they were able to find. There are about 50 to 60 rows of scales counting backward two head lengths from the upper angle of the opercle. The gill rakers are short, with 10 on the lower limb of the first arch.

The teeth in the upper jaw are in a narrow villiform band with the outer series enlarged and curving slightly inward. In the lower jaw the teeth are grouped irregularly in several rows near the symphysis, and are in two rows and then one row going toward the angle of the mouth. The lower teeth are all about the same size and somewhat smaller than the large upper series.

The first dorsal spine is very short and covered with skin. The second spine, 1.5 in the head, has rather weak serrations, the lower one-fifth or one-sixth being smooth or having appressed spinules. Toward the tip of the serrated ray the spinules extend outward to an angle of about 30°. The length of the dorsal rays is from one-half to an eye's diameter, while the anal rays are about 1½ the eye.

Seven specimens taken by "Atlantis" have been compared with the type in the M.C.Z. (Cat. No. 28005). They were taken in four closely spaced Blake-trawl hauls in the vicinity of 39° to 40° N. latitude and 68° longitude, July 26–27, 1939, in depths ranging from 1100 to 1325 fathoms.

This species is known from the western North Atlantic between the offing of Chesapeake Bay and the eastern slope of Georges Bank, and from the eastern Atlantic near the Canary Islands, the Azores and to the northward of the Azores in depths varying from 665 to 1730 fathoms. A locality of 29° 22′ N. latitude given by Goode and Bean (1896: 405) is an error and should be 39° 22′ N.

Gadidae

Antimora rostrata Günther, 1878

Antimora rostrata Günther, Ann. Mag. Nat. Hist., 5, II, 1878: 18.
Haloporphyrus viola Goode and Bean, Proc. U. S. Nat. Mus., 1, 1878: 257.
Antimora microlepis Bean, Proc. U. S. Nat. Mus., 13, 1890: 38.
Antimora rhina Garman, Mem. Mus. Comp. Zool., 24, 1899: 185.

Antimora rostrata Günther and *Haloporphyrus viola* Goode and Bean were found by Koefoed (1932: 118) to be synonymous and this was substantiated by a study of material in the M.C.Z. collection. Differences may

exist among specimens taken in the same haul or in the same immediate locality. For example, the snout is rounded on a 477 mm. specimen, more acute on a 486 mm. fish and still more acute on one of 246 mm. Three fish, 115, 128 and 327 mm. long have a small but sharp protuberance at the tip of the snout, lacking on other specimens of various sizes.

From five "Atlantis" specimens 246 to 486 mm. in total length, the following proportions were obtained: head 3.8 to 4.4 in standard length; eye 3 (smallest fish) to 4.5 (largest fish); snout 3 to 3.2; interorbital 3.2 (large fish) to 4.2 (small fish), in head. Dorsal 4 or 5, 53 to 55; anal 39 to 42; scales in 137 to 143 rows; gill rakers 5 + 11 (one specimen). The tail is square or emarginate and usually frayed at the end.

Bean's (1891: 35) description of *Antimora microlepis* agrees well with those given for *A. viola* and *A. rostrata.*

A specimen labeled *microlepis* in the collection of the M.C.Z. (Cat. 28250, Albatross Sta. 3344, off coast of Washington) gave the following proportions: total length 166 mm.; head 3.7; eye 3.6; snout 3; interorbital 4.2; dorsal 4,54; anal 40; scales ca. 145; gill rakers 11 on lower limb. Snout rounded, with small protuberance at tip. Laid beside specimens of *rostrata* of nearly the same size no significant external differences were noted.

Garman's types of *A. rhina* (M.C.Z. nos. 28610, 28611, 3 specimens 263-292 mm. long) could not be separated from specimens of *A. rostrata.* A fish 286 mm. was as follows: head 4.1; eye 3.7; snout 3; interorbital 4.1; dorsal 5,52; anal 40; scales ca. 140; gill rakers on lower limb 12, including 3 rudiments. Another specimen had 12 and no rudiments. Snout rounded, rather sharp at tip but with no definite protuberance.

The habitat of *A. rostrata* as now defined includes the North and South Atlantic Oceans (Newfoundland to Uruguay; northern Europe) eastern Pacific Ocean (Canada, Washington, Panama) and the southern Indian Ocean (between Kerguelen Island and the Cape of Good Hope; and Marion Island). The depth range is from 306 to 1456 fathoms.

The "Atlantis" collection includes 6 specimens taken the summers of 1937, 1938 and 1939 from several localities in the vicinity of 39°–40° N. latitude and 68°–72° W. longitude in a depth range of 820–1230 fathoms.

Caulolepidae

Caulolepis longidens Gill, 1883

Caulolepis longidens Gill, Proc. U. S. Nat. Mus., 4, 1883: 258.
Caulolepis subulidens Garman, Mem. Mus. Comp. Zool., 24, 1899: 60, pl. B.

Depth 1.8 to 2.3; head 2.5 to 2.9; eye 4.8 to 5.2; snout 3.8 to 4.; interorbital 2.8 to 3.4; D. 18 to 20; A. 9 or 10; P. 15 or 16; V. 7.

These proportions and counts are based on four specimens in the M.C.Z. collection from the North Atlantic. Garman's type of *C. sublidens,* from the Pacific, could not be separated from *longidens.* The anal count of Garman's type was found to be 9 instead of 8 as given in the original description (Garman, 1899: 60).

One specimen, 133 mm. long, was taken in Lat. 39° 28′ N., Long, 71° 58′ W., in a Blake-trawl which fished bottom in 640 fathoms, August 11, 1937.

East coast of North America from the Caribbean to the southern slope of Georges Bank; mid-Atlantic; Gulf of Guinea; Azores; in the Pacific off San Diego and Panama, down to 1832 fathoms.

BROTULIDAE

Dicrolene intronigra Goode and Bean, 1882

One specimen, 281 mm. long, from Lat. 39° 28′ N., Long. 71° 58′ W., in 640 fathoms, August 11, 1937.

Known from the Caribbean Sea, Gulf of Mexico and northward along the eastern coast of the United States to Lat. 41° 53′ N., off northwest and the northeast coasts of Africa, Arabian Sea, Bay of Bengal. Most of the captures have been in 464-982 fathoms but Koefoed (1932: 134) records a specimen from about 5000 meters (2734 fathoms).

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MUSEUM OF COMPARATIVE ZOOLOGY, CAMBRIDGE, MASSACHUSETTS.

Report of the year 1939

THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

REPORT FOR THE YEAR 1939

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(As of January 1, 1940)

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Frank R. Lillie, 5801 Kenwood Avenue, Chicago, Ill.
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B. W. St. Clair, 10 Arrow Street, Cambridge, Mass.

To serve until 1940

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William Bowie, 2900 Connecticut Avenue, Washington, D. C.
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Ex Officio

Columbus O'D. Iselin, Woods Hole Oceanographic Institution, Woods Hole, Mass.
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Henry B. Bigelow, President of the Corporation, Museum of Comparative Zoölogy, Cambridge, Mass.
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Columbus O'D. Iselin, Clerk of the Corporation, Woods Hole Oceanographic Institution, Woods Hole, Mass.

II. MEMBERS OF THE CORPORATION

(As of January 1, 1940)

Charles Francis Adams, 15 State Street, Boston, Mass.
Thomas Barbour, Museum of Comparative Zoölogy, Cambridge, Mass.
Henry B. Bigelow, Museum of Comparative Zoölogy, Cambridge, Mass.
William Bowie, 2900 Connecticut Avenue, Washington, D. C.
Isaiah Bowman, Johns Hopkins University, Baltimore, Md.
The Commandant (Admiral R. R. Waesche), U. S. Coast Guard, for the time being, Washington, D. C.
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A. G. Huntsman, University of Toronto, Toronto, Canada
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Albert E. Parr, Bingham Oceanographic Foundation, New Haven, Conn.
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Henry L. Shattuck, 50 Federal Street, Boston, Mass.
T. Wayland Vaughan, 3333 P Street, Washington, D. C.

III. REPORT OF THE TREASURER

To The Members and Trustees of the
Woods Hole Oceanographic Institution:

Gentlemen:

The accounts for the year 1939 have been audited by Messrs. Stagg, Mather & Hough, public accountants.

During the year bonds costing $399,978.75 were sold at a profit of $9,911.25 to which must be added $2,491.91 the reserve for amortization of bond premium applicable to these bonds. There was invested from endowment fund cash $289,002.50 in bonds and $152,264.57 in stocks.

The Special Income account in which extra dividends are placed, increased by $4,501.33 to which $725. not earmarked as extras on receipt but so determined by the auditors is to be added.

The entire appropriation for the Depreciation Fund $4,800. was used for replacements on "Atlantis" so that no cash was transferred.

Contributions toward running expenses were received as follows, from

Bermuda Aquarium	$1,000.00
University of Havana	350.00
Carnegie Corporation	283.26

The gross income on the securities in the Endowment Fund at the end of the year was about, .0407 of the cost of those securities, and .0413 of their then market value.

The total expenses exceeded the budget by $5,824.83 but were under the total income (including special income of $3,862.33) by $3,416.45.

The reserve for "working balance" having fulfilled its purpose was transferred to surplus.

Summaries of the balance sheet and comparative income and expense statements for 1939 and 1938 appear on pages 6 to 8.

Respectfully submitted,
Lawrason Riggs, Jr.,
Treasurer

BALANCE SHEET

ENDOWMENT FUND ASSETS

	Quoted Market Value		
Endowment fund assets:			
Bonds (less reserve for amortization of bond premiums $6,017.01)	$1,275,847.50	$1,321,306.25	
Stocks	$1,140,702.11	1,126,398.70	
Cash		3,427.88	$2,451,132.83
Reserve fund assets:			
Bonds	$ 5,655.00	$ 5,510.00	
Stocks	$ 14,765.63	19,099.02	
Cash		3,306.32	27,915.34
			$2,479,048.17

PLANT ASSETS

Laboratory plant:		
Land	$ 27,072.32	
Buildings	323,213.12	
Laboratory equipment	21,361.93	
Crew room equipment	557.95	
Library	11,300.00	$ 383,505.32
Ship "Atlantis":		
Construction	$ 218,674.47	
Equipment	27,298.50	245,972.97
Small boat and equipment		6,570.55
		$ 636,048.84
Depreciation fund assets (for periodic replacements):		
Bonds (quoted market value $30,932.50)	$ 31,592.50	
Cash	2,753.64	34,346.14
		$ 670,394.98

CURRENT ASSETS

Current funds—Cash	$ 6,484.21	
Less—Due to special income cash	725.00	$ 5,759.21
Special income assets:		
Investments:		
Bonds (quoted market value $10,300.00)	$ 10,235.00	
Stocks (quoted market value $1,119.38)	1,236.16	
Cash (including $725.00 due from current funds—Cash)	13,376.03	24,847.19
Interest accrued at date of acquisition on bonds purchased		903.46
		$ 31,509.86

DECEMBER 31, 1939

ENDOWMENT FUNDS

Endowment Fund—General	$2,000,000.00	
Endowment fund—For upkeep of plant	419,419.96	
	$2,419,419.96	
Add—Accumulated net gain on securities called or sold	31,712.87	$2,451,132.83
Reserve fund	$ 23,395.57	
Add—Accumulated reserve fund income	4,519.77	27,915.34
		$2,479,048.17

PLANT FUND

Plant fund—General	$ 607,642.13	
Plant fund reserve—Transferred in prior years from current surplus	28,406.71	$ 636,048.84
Reserve for depreciation (for periodic replacements)		34,346.14
		$ 670,394.98

CURRENT LIABILITIES AND SURPLUS

Accounts payable		$ 1,392.76
Current surplus:		
Balance at December 31, 1938	$ 21,700.65	
Add:		
Transfer of reserve for "working balance"	5,000.00	
Excess of income over expenses for the year ended December 31, 1939	3,416.45	30,117.10
		$ 31,509.86

STATEMENT OF INCOME FROM ENDOWMENT FUND INVESTMENTS AND CURRENT ASSETS AND EXPENSES APPLICABLE THERETO, INCLUDING EXPENDITURES FOR PERMANENT PLANT ADDITIONS

FOR THE YEARS ENDED DECEMBER 31, 1939 AND DECEMBER 31, 1938

		Year Ended December 31, 1939			Year Ended December 31, 1938		
Income:							
Income from endowment funds:							
Interest (including in 1939 special income of $442.83)		$60,174.44			$63,530.07		
Dividends (including in 1939 special income of $3,419.50)		53,942.52			46,154.77		
			$114,116.96			$109,684.84	
Less—Custodian fees and expenses			1,508.94			1,490.73	
			$112,608.02			$108,194.11	
Contributions received for operating expenses			1,633.26			1,000.00	
Total income				$114,241.28			$109,194.11
Expenses:	*Budget*						
Upkeep of plant:							
Upkeep of buildings and grounds	$ 6,625.00	$ 7,015.20			$ 8,893.99		
Upkeep of "Atlantis"	8,100.00	9,423.10			12,629.42		
Upkeep of "Asterias"	100.00	833.91			120.36		
Insurance	5,900.00	5,658.17			5,833.90		
Depreciation	4,800.00	4,800.00			4,800.00		
	$ 25,525.00		$ 27,730.38			$ 32,277.67	
Operating expenses:							
Operation of "Atlantis"	$ 30,500.00	$33,640.26			$29,919.11		
Operation of "Asterias"	850.00	807.32			1,289.44		
Scientists' salaries	27,125.00	26,369.87			26,875.51		
Scientific supplies and equipment	5,000.00	6,013.52			6,699.13		
Traveling expenses	750.00	1,149.79			856.25		
Publications	3,500.00	3,053.37			2,917.06		
Administration	7,425.00	7,640.45			7,497.85		
Amortization of bond premiums	2,000.00	2,242.95			1,586.32		
Contribution to retirement fund	1,500.00	1,576.92			1,567.38		
Not allocated	225.00	—			—		
	$ 78,875.00		82,494.45			79,208.05	
Total expenses	$104,400.00		$110,224.83			$111,485.72	
Expenditures for permanent plant additions:							
Additions to library	$ 600.00		600.00			600.00	
	$105,000.00			110,824.83			112,085.72
Excess of income over expenses for 1939				$ 3,416.45			
Excess of expenses over income for 1938							$ *2,891.61*

IV. TENTH ANNUAL REPORT OF THE DIRECTOR FOR THE YEAR 1939

BY HENRY B. BIGELOW

Equipment

As the result of the hurricane of September, 1938, an unusual amount of outdoor repairs was required. The most important items were resetting stone blocks in the sea wall, reconditioning the lawns and resurfacing the driveway. The total cost of this work was $1725.

Last spring the "Atlantis' " mainmast was lifted out for inspection and all standing rigging was renewed. At the same time the bearings of the main engine were opened up and adjusted. During the autumn at Woods Hole, the major part of Lloyd's eight year survey was completed while the crew was busy for a month at painting and scraping.

On "Asterias" the engine was completely reconditioned during the winter. Both the vessels are now in excellent condition.

The most important additions to the scientific equipment have been 30,000 feet of special one half inch dredging cable; a Monroe calculating machine; a bench lathe, a set of Assman psychrometers with reversing thermometers; four aerometers for Professor Spilhaus' work; and a refrigerating tank for constant temperature experiments.

Accidents

On the Cuban cruise, the bow gallows of "Atlantis" carried away while being used in otter trawling, but it has since been repaired.

I regret to have to report the death of one of our foremast hands, George Temple Priest, in the smash-up of Coast Guard plane V-164 on July 15th.

Loans

We have neither made any important loans nor have we borrowed any apparatus of special mention.

Library

Our contribution to the library of the Marine Biological Laboratory was the same this year as last, namely $600. In the past year the following items were purchased: 12 books, 1 back set completed, 40 current subscriptions, and the binding of 77 current and back volumes. Seventy-two journals were received by exchange and 9 by gift, also 432 other journal numbers and reprints making a total of 513 publications added to the library.

Personnel

The only change in the scientific staff was the appointment of Mr. Charles M. Weiss as bacteriological technician to succeed Mr. D. Q. Anderson.

Fellowship holders who have worked at the laboratory during the summer are: Mr. Kenneth J. Arnold, Mr. William Gosline, Mr. Robert H. Hay, Dr. Charles W. Hock, Dr. Blodwen Lloyd, Mr. Arnold N. Morton, Professor L. V. Whitney and Dr. Claude E. ZoBell. Miss Frances L. Parker, Dr. Lois C. Lillick and Dr. Th. von Brand worked under special grants.

Twelve assistants have worked for various members of the staff and visiting investigators and there were nine volunteer workers. Dr. Seiwell employed Mr. Andrew Stergion under a grant from the American Philosophical Society.

The following visiting investigators have worked in the Institution: Dr. A. A. Abramowitz, Professor V. W. Ekman from Sweden, Dr. Maurice Ewing, Mr. H. B. Hachey, Dr. F. Ronald Hayes, Dr. Dixie Pelluet Hayes, Dr. F. L. Hisaw, Dr. Margaret Hotchkiss, Mr. John Lochhead, Mrs. Margit Lochhead, Mrs. Helen N. Moore, Dr. Clinton M. Osborn, Dr. G. H. Parker, Dr. Robert W. Pennak, Dr. Austin Phelps, Dr. E. F. Thompson, Dr. Abby H. Turner and Dr. George Wald. Among the visitors were Dr. Martin Knudsen from Copenhagen, Dr. R. H. Fleming, Scripps Institution of Oceanography, La Jolla, California, Dr. Koji Hidaka, Imperial Marine Observatory, Kobe, Japan and Dr. Wiseman, The Laboratory, Plymouth, England.

The following institutions were represented during the year in the laboratory or on cruises of "Atlantis": Barat College, Barnard College, Bermuda Biological Station, Brown University, Columbia University, Connecticut College, Cushman Laboratory for Foraminiferal Research, Dalhousie University, Fouke Fur Company, Harvard University, Massachusetts Institute of Technology, Mt. Holyoke College, New York Medical College, New York University, Queen's University, Rutgers University, Royal Technical College, Glasgow Scotland, Scripps Institution of Oceanography, Southwest Missouri State Teachers College, Stanford University, Submarine Signal Company, U. S. Coast Guard, University of Colorado, University of Havana, University of Texas, University of Washington, Wellesley College and Yale University; a total of 29, or 13 more than last year. More than one hundred persons have worked at the Institution, and this is the first year of operation in which every room in the laboratory has been in service.

There have been no changes in the officers of "Atlantis." "Asterias" was in charge of Lincoln Dow, assisted by William Butcher, Edmund Billings and Henry K. Porter.

The following members of our staff have acted, on one occasion or another, as scientist in chief in charge of "Atlantis": G. L. Clarke, Wm. C. Schroeder, H. R. Seiwell, A. F. Spilhaus, Henry C. Stetson, E. E. Watson and Alfred Woodcock.

Travel

In late August Dr. R. B. Montgomery returned from a year's visit in Europe where he visited laboratories in Germany, Finland and the Scandinavian countries.

Publications

Number 3 of Volume VII of "Papers in Physical Oceanography and Meteorology" appeared.

The following contributions were published during the year:

No. 173. Soule, Floyd M. Oceanography. Excerpt from International Ice Observation and Ice Patrol Service in the North Atlantic Ocean, Season of 1937. U. S. Coast Guard Bull., No. 27, pp. 71–126. 1938.

No. 191. Todd, Jean P. Shoal-water Deposits of the Bermuda Banks. Jour. Sed. Pet., Vol. 9, No. 1, pp. 8–13. 1939.

No. 192. Seiwell, H. R. Die Verwendung der Verteiling von Sauerstoff auf die physische Ozeanographie des Karibischen Meeresgebietes. Gerlands Beiträge zur Geophysik, Bd. 54, Heft 4, pp. 1–7. 1939.

No. 193. Clarke, George L. and Harry R. James. Laboratory Analysis of the Selective Absorption of Light by Sea Water. Jour. Optical Soc. Amer., Vol. 29, pp. 43–55. 1939.

No. 194. Bigelow, Henry B. and Mary Sears. Studies of the Waters of the Continental Shelf, Cape Cod to Chesapeake Bay. III. A Volumetric Study of the Zooplankton. Mem. Mus. Comp. Zool., Vol. LIV, No. 4, pp. 183–378. 1939.

No. 195. Wald, George. On the Distribution of Vitamins A_1 and A_2. Jour. Gen. Physiol., Vol. 22, No. 3, pp. 391–415. 1939.

No. 196. Redfield, Alfred C. The History of a Population of *Limacina retroversa* during its Drift across the Gulf of Maine. Biol. Bull., Vol. LXXVI, No. 1, pp. 26–47. 1939.

No. 197. Hsiao, Sidney C. T. The Reproductive System and Spermatogenesis of *Limacina* (*Spiratella*) *retroversa* (Flem.). Biol. Bull., Vol. LXXVI, No. 1, pp. 7–25. 1939.

No. 199. Chace, Fenner A., Jr. Reports on the Scientific Results of the First *Atlantis* Expedition to the West Indies, under the joint Auspices of the University of Havana and Harvard University. Preliminary Descriptions of One New Genus and Seventeen New Species of Decapod and Stomatopod Crustacea. Mem. Soc. Cub. Hist. Nat., Vol. 13, No. 1, pp. 31–54. 1939.

No. 201. Clarke, George L. The Utilization of Solar Energy by Aquatic Organisms. Amer. Assoc. Adv. Sci., Publ. No. 10, pp. 27–38. 1939.

No. 202. Osborn, Clinton M. The Physiology of Color Change in Flatfishes. Jour. Exper. Zool., Vol. 81, No. 3, pp. 479–515. 1939.

No. 203. Burkenroad, Martin D. Further Observations on Penaeidae of the Northern Gulf of Mexico. Bull. Bing. Oceanographic Coll., Vol. VI, Art 6, pp. 1–62. 1939.

No. 204. Phleger, Fred B., Jr. Foraminifera of Submarine Cores from the Continental Slope. Bull. Geol. Soc. Amer., Vol. 50, pp. 1395–1422. 1939.

No. 205. Waterman, Talbot H., Rudolf F. Nunnemacher, Fenner A. Chace, Jr., and George L. Clarke. Diurnal Vertical Migrations of Deep-water Plankton. Biol. Bull., Vol. LXXVI, No. 2, pp. 256–279. 1939.

No. 206. Hsiao, Sidney C. T. The Reproduction of *Limacina retroversa* (Flem.). Biol. Bull., Vol. LXXVI, No. 2, pp. 280–303. 1939.

No. 207. Johnson, W. H. and J. E. G. Raymont. The Reactions of the Planktonic Copepod, *Centropages typicus*, to Light and Gravity. Biol. Bull., Vol. LXXVII, No. 2, pp. 200–215. 1939.

No. 208. Toth, Louis A. Renal and Vascular Responses to Epinephrine Injections in Glomerular and Aglomerular Fish. Amer. Jour. Physiol., Vol. 126, No. 2, pp. 347–353. 1939.

No. 209. Young, John A., Jr. Minerals from Deep Sea Cores and Surface Deposits of Bermudian Calcareous Sediments. Amer. Jour. Sci., Vol. 237, pp. 798–810. 1939.

No. 210. Bigelow, Henry B. and William C. Schroeder. Notes on the Fauna above Mud Bottoms in Deep Water in the Gulf of Maine. Biol. Bull., Vol. LXXVI, No. 3, pp. 305–324. 1939.

No. 211. Waterman, Talbot Howe. Studies of Deep-sea Angler-fishes (Ceratioidea). I. An Historical Survey of our Present State of Knowledge. II. Three New Species. Bull. Mus. Comp. Zool., Vol. LXXXV, No. 3, pp. 65–94. 1939.

No. 212. Clarke, George L. The Relation between Diatoms and Copepods as a Factor in the Productivity of the Sea. Quart. Rev. Biol., Vol. 14, No. 1, pp. 60–64. 1939.

No. 213. Abramowitz, A. A. The Pituitary Control of Chromatophores in the Dogfish. Amer. Nat., Vol. LXXIII, pp. 208–218. 1939.

No. 214. Clarke, George L. and David D. Bonnet. The Influence of Temperature on the Survival, Growth and Respiration of *Calanus finmarchicus*. Biol. Bull., Vol. LXXVI, No. 3, pp. 371–383. 1939.

No. 216. Ketchum, Bostwick H. The Absorption of Phosphate and Nitrate by Illuminated Cultures of *Nitzschia Closterium*. Amer. Jour. Bot., Vol. 26, No. 6, pp. 399–407. 1939.

No. 217. Seiwell, H. R. Some Applications of Statistical Methods to Problems in Modern Physical Oceanography. Proc. Industrial Statistics Conference, held at Mass. Inst. Tech., Sept. 8 and 9, 1938. Pitman Publishing Corporation, pp. 156–173. 1939.

No. 218. Bermúdez, Pedro J. Resultados de la Primera Expedicion en las Antillas del Ketch *Atlantis* bajo los Auspicios de las Universidades de Harvard y Habana. Nuevo Género y Especies Nuevas de Foraminiferos. Mem. Soc. Cub. Hist. Nat., Vol. 13, No. 1, pp. 9–12. 1939.

No. 219. Ketchum, Bostwick H. The Development and Restoration of Deficiencies in the Phosphorus and Nitrogen Composition of Unicellular Plants. Jour. Cell. and Comp. Physiol., Vol. 13, No. 3, pp. 373–381. 1939.

No. 220. Iselin, C. O'D. The Influence of Vertical and Lateral Turbulence on the Characteristics of the Waters at Mid-depths. Trans. Am. Geophys. Union, pp. 414–417. 1939.

No. 221. Iselin, C. O'D. Some Physical Factors which may Influence the Productivity of New England's Coastal Waters. Sears Found. Jour. Mar. Res., Vol. II, No. 1, pp. 74–85. 1939.

No. 222. Von Brand, Theodor, Norris W. Rakestraw and Charles E. Renn. Further Experiments on the Decomposition and Regeneration of Nitrogenous Organic Matter in Sea Water. Biol. Bull., Vol. LXXVII, No. 2, pp. 285–296. 1939.

No. 223. Seiwell, H. R. *Atlantis* Cruise to the Tropical North Atlantic, January to March, 1939. Trans. Am. Geophys. Union, pp. 418–422. 1939.

No. 224. Clench, W. J. and C. G. Aguayo. Notes and Descriptions of New Deep-water Mollusca obtained by the Harvard-Habana Expedition off the Coast of Cuba. II. Mem. Soc. Cub. Hist. Nat., Vol. 13, pp. 189–197. 1939.

No. 225. Bermúdez, Pedro J. Resultados de la Primera Expedicion en las Antillas del Ketch *Atlantis* bajo los Auspicios de las Universidades de Harvard y Habana. Foraminiferos del Género Recurvoides, descripción de una Especie Nueva. Mem. Soc. Cub. Hist. Nat., Vol. 13, No. 2, pp. 57–61. 1939.

No. 226. Seiwell, H. R. The Effect of Short Period Variations of Temperature and Salinity on Calculations in Dynamic Oceanography. Papers in Physical Oceanography and Meteorology, Vol. VII, No. 3, pp. 1–32. 1939.

No. 227. Seiwell, H. R. Daily Temperature Variations in the Western North Atlantic. Jour. d. Conseil, Vol. XIV, No. 3, pp. 357–369. 1939.

No. 228. Rakestraw, Norris W., Clifford E. Herrick, Jr., and Wm. D. Urry. The Helium-Neon Content of Sea Water and its Relation to the Oxygen Content. Jour. Amer. Chem. Soc., Vol. 61, pp. 2806–2807. 1939.

No. 229. Brooks, Edward M. Transport and Convergence of the North Atlanic Drift Current Computed from the Average January Pressure Distribution. Sears Found. Jour. Mar. Res., Vol. II, No. 2, pp. 163–167. 1939.

No. 230. Soule, Floyd M. Consideration of the Depth of the Motionless Surface near the Grand Banks of Newfoundland. Sears Found. Jour., Mar. Res., Vol. II, No. 3, pp. 169–180. 1939.

No. 232. Riley, Gordon A. Plankton Studies. II. The Western North Atlantic, May–June, 1939. Sears Found. Jour. Mar. Res., Vol. II, No. 2, pp. 145–162. 1939.

No. 233. Nichols, J. T. Young Caranx in the Western North Atlantic. Bull. Bingham Oceanographic Coll., Vol. VII, Art 2, pp. 1–9. 1939.

No. 234. Parr, Albert Eide. Quantitative Observations on the Pelagic Sargassum Vegetation of the Western North Atlantic. Bull. Bingham Oceanographic Coll., Vol. VI, Art. 7, pp. 1–94. 1939.

No. 236. Clarke, George L. Variation in the Transparency of Three Areas of the Atlantic throughout the Year. Ecology, Vol. 20, No. 4, pp. 529–543. 1939.

No. 238. Anderson, D. Q. Distribution of Organic Matter in Marine Sediments and its Availability to Further Decomposition. Sears Found. Jour. Mar. Res., Vol. II, No. 3, pp. 225–235. 1939.

No. 243. Bermúdez, Pedro J. Resultado de la Primera Expedicion en las Antillas del Ketch *Atlantis* bajo los Auspicios de las Universidades de Harvard y Habana. Nueva Género y Especies Nuevas de Foraminiferos. Mem. Soc. Cub. Hist. Nat., Vol. 13, No. 4, pp. 247–251. 1939.

Coöperation

The investigations of the Gulf Stream System in which we coöperate with the Bermuda Biological Station have continued, and 6 profiles were run by "Atlantis" during the year. From the middle of March to May, "Atlantis" carried out a second trawling campaign in deep water around Cuba in coöperation with Harvard University, the University of Havana and the Bermuda Aquarium, the last two institutions contributing substantially to the expenses of the cruise. Mr. William C. Schroeder was the scientist in charge, and was accompanied by Dr. Luis Howell Rivero of the University of Havana. Out of 142 successful hauls, made in depths ranging from 200–1500 fathoms, approximately 1000 species of fishes and invertebrates were taken, of which perhaps 60–70 will prove to be new to science. There was a particularly good catch of crinoids. We are again in debt to the Cuban Government for many courtesies to the ship.

The tide gauge mentioned in my last report was operated at Cat Cay throughout the year, also the one on our own dock in Woods Hole. A preliminary investigation of the relationship of Gulf Stream velocities to shift in main sea level have proved most encouraging.

We received from the Carnegie Corporation a further contribution of $283 toward the operating expenses of "Asterias," out of Gloucester, in late March and early April. Diatoms were collected in large amount for the use of Dr. Hans Clarke, in continuation of his investigations in their chemical composition. Finally, our coöperation with the U. S. Coast Guard, through the International Ice Patrol Service, continues a close one; the oceanographer of the Patrol having his land headquarters here, and being in frequent consultation with the physical oceanographers on our staff.

Field Work

Operations of "Atlantis" for the year 1939:

Cruise 83: January–June; two Gulf Stream sections, survey of the eastern part of the Northern Equatorial current and bottom dredging around Cuba.

Cruise 84: July; Gulf Stream section.

Cruise 85: July; southern edge of Georges Bank.

Cruise 86: August; anchor station south of Montauk Point.

Cruise 87: August; Gulf Stream section.

Cruise 88: August; light intensity measurements.

Cruise 89: September; biological survey of Georges Bank.

Cruise 90: September; continental slope south of Woods Hole.

Cruise 91: October; Gulf Stream section and anchor station.

Cruise 92: November; Gulf Stream section.

Summary of observations:

Total distance sailed	16,976
Number of days at sea	236
Deep hydrographic stations	416
Shallow hydrographic stations	106
Serial temperature lowerings of internal waves	340
Plankton hauls	556
Bottom trawl hauls	183
Bottom samples	42

"Asterias" was put in commission on March 23d, and first spent two weeks collecting diatoms out of Gloucester. During the summer she was used for the usual short trips near Woods Hole and in Massachusetts Bay.

Staff Meetings

Nine staff meetings were held during the summer. The speakers were: Dr. George L. Clarke, Professor V. W. Ekman, Mr. Columbus O'D. Iselin, Dr. Norris W. Rakestraw, Dr. Charles E. Renn, Dr. H. R. Seiwell, Mr. Floyd M. Soule, Dr. E. E. Watson and Dr. Claude E. ZoBell.

A series of meetings was also held to plan work on Georges Bank.

Financial

We received from the insurance on "Atlantis" a refund of $1598. mainly as the result of sickness and injury claims. From the Carnegie Corporation we received $283; from the University of Havana $350 and from Mr. Jay Holmes in behalf of the Bermuda Aquarium $1,000 toward the Cuban trip; and from an anonymous source a gift of $170.

V. STAFF

(As of December 31, 1939)

Henry B. Bigelow, Professor of Zoölogy, Harvard University, Director

Cornelia L. Carey, Assistant Professor of Botany, Barnard College, Research Associate in Marine Bacteriology

George L. Clarke, Tutor and Instructor in Biology, Harvard University, Junior Biologist

Columbus O'D. Iselin, Associate Professor of Physical Oceanography, Harvard University, and Assistant Curator of Oceanography, Museum of Comparative Zoölogy, Research Associate in Physical Oceanography

R. B. Montgomery, Junior Oceanographer

A. E. Parr, Director of Peabody Museum and Curator of the Bingham Oceanographic Collection, Yale University, Research Associate in Oceanography

Norris W. Rakestraw, Associate Professor of Chemistry, Brown University, Research Associate in Physical Chemistry

Alfred C. Redfield, Professor of Physiology, Harvard University, Research Associate in Biology

C. E. Renn, Tutor in Biology and Instructor in Sanitary Engineering, Harvard University, Junior Marine Bacteriologist

C.-G. Rossby, Professor of Meteorology, Massachusetts Institute of Technology and Assistant Chief, U. S. Weather Bureau, Oceanographer

Mary Sears, Instructor in Zoölogy, Wellesley College, Junior Biologist

H. R. Seiwell, Investigator in Oceanography

Floyd M. Soule, Senior Physical Oceanographer, U. S. Coast Guard, Research Associate in Oceanography

Athelstan F. Spilhaus, Assistant Professor of Meteorology, New York University, Investigator in Physical Oceanography

Henry C. Stetson, Research Associate in Paleontology, Museum of Comparative Zoölogy, Research Associate in Submarine Geology

Selman A. Waksman, Microbiologist, New Jersey Agricultural Experiment Station, Marine Bacteriologist

E. E. Watson, Assistant Professor of Physics, Queen's University, Research Associate in Physical Oceanography

Dean F. Bumpus, Biological Technician

Sidney C. T. Hsiao, Technician in Physical Oceanography

Charles M. Weiss, Bacteriological Technician

Alfred Woodcock, Oceanographic Technician

William C. Schroeder, Business Manager

Mrs. Virginia Walker Smith, Secretary and Administrative Assistant

William Schroeder, Superintendent of Buildings and Grounds

APPENDIX

Reports of progress by investigators working at the Institution during 1939.

ZOÖPLANKTON STUDIES

HENRY B. BIGELOW AND MARY SEARS

1. The study of the medusae collected on the "Zaca" expeditions of 1936 and 1938 is now completed and the report has been submitted for publication. (Bigelow)

2. The study of the "Dana" collection of siphonophores is still in progress. (Bigelow and Sears)

3. The completed report on the zooplankton of the continental shelf, Cape Cod-Chesapeake Bay, appeared in July as a "Memoir of the Museum of Comparative Zoölogy." (Bigelow and Sears)

4. A study of the zooplankton on the line running SSE from Montauk Point across the Gulf Stream toward Bermuda was commenced on the periodic cruise in July, to learn about annual fluctuations in the plankton on the continental shelf and to follow the seasonal cycle in the plankton of the slope water, Gulf Stream and Sargasso Sea. (Sears)

LIGHT PENETRATION AND QUANTITATIVE ZOÖPLANKTON STUDIES

GEORGE L. CLARKE

1. *Transparency of oceanic areas.* Measurements of light penetration made throughout the year at stations on the Montauk-Bermuda section showed that the coastal water was the least transparent on all occasions, the Sargasso water was the clearest, and the slope water intermediate. Variation in transparency was greatest in the slope water area and is accounted for by the fluctuations in the amounts of Sargasso water and coastal water present. The variations in the other areas are not correlated directly with the plankton but may be, indirectly, through its disintegration products. Important changes in the illumination reaching the deeper strata were produced by only slight variations in transparency.

2. *Comparative richness of plankton in oceanic areas.* The investigation of the fluctuations in the abundance of the zooplankton throughout the year in the coastal area, in the slope water area, and in the Sargasso Sea has been completed. An unexpectedly great seasonal difference in the abundance of the plankton was encountered, the average volume of the catches in the warm half of the year being as much as 20× to 40× greater than in the winter in the coastal

area and as much as 10× greater in the slope water area. The survey has made possible a quantitative comparison of the richness of coastal and off-shore regions. The average volume of the coastal area plankton for the whole year was about 4× greater than that of the slope water area, and the latter was about 4× greater than at the Sargasso Sea station. When the total volumes and the species composition of the catches were compared with the previous year and with earlier investigations, the occurrence of important annual fluctuations was revealed.

3. *Development of quantitative methods of plankton collection.* The method of collecting diatoms from the sea in sufficient quantity for chemical analysis was further developed and put into operation during April off Gloucester. Diatom sludge was obtained with this method at the rate of a pint in three hours. The plankton samplers with volume meters, developed last year for zooplankton, were perfected and operated satisfactorily during the year. The variation in seven series of oblique, vertical, and horizontal plankton hauls with nets of the same size as those used with the plankton samplers and with larger nets was studied statistically (in collaboration with C. P. Winsor). No significant difference in variability of catches was observed with different sizes of nets. The proportions of different groups caught by the various nets did not vary in a manner to indicate differential selection with net size. Therefore our smallest net was as reliable for the types of zooplankton considered (chiefly copepods) as nets of more usual size.

4. *Laboratory culture of planktonic animals.* The study of the survival and growth of important species of copepods in relation to temperature, food and other environmental conditions was continued and an additional species, *Metridia lucens*, was brought under culture. The animals lived as long as two months, under suitable conditions, without change of water, but contrary to expectation, the copepods throve as well in freshly collected sea water as in stored water. Experiments were also conducted on the development of haddock and cod eggs. Large numbers of cod eggs were hatched at four temperatures and the larvae were cultured for several weeks. Success was attained for the first time in inducing the cod fry to feed after the yolk sac had been absorbed and hence to continue growth in the laboratory beyond this stage.

5. *Quantitative plankton survey of a fishing bank.* A close net-work of 52 stations was made on Georges Bank during a ten day period in September, thus constituting a more intensive study of the biological conditions over a fishing bank than previously possible. The abun-

dance and conditions of growth of the phytoplankton at these stations were investigated by G. A. Riley. The material obtained and the observations made are now in the process of analysis.

STUDIES ON FISHES

WILLIAM GOSLINE

The redfish (*Sebastes marinus*) was studied with particular reference to growth rate. Length frequencies of commercial sizes and of the small fish available were taken. The possibility of reading age from the otoliths and opercular bones was investigated, but the greatest part of the work was devoted to a study of the scales.

DIRECT MEASUREMENT OF CURRENTS

ROBERT H. HAY

The Watson current meter was adapted for the study of bottom velocities in shallow coastal waters. The time from June 8 to August 14 was taken up with construction of auxiliary apparatus and with careful tests of it and the meter. From August 14 to August 30 four stations were made, three in Buzzards Bay and one in Vineyard Sound. Velocity and direction readings were taken at heights above bottom of 22, 54 and 87 cm. in such a manner as to give a synoptic set of average velocities at these heights. The total time on station was in all but one case over six hours. Preliminary examination of these data has shown that the velocity averages can be plotted against height to give smooth curves. However, plots of velocity against log height did not yield straight lines, nor did the average velocities, or points extrapolated from the curves, seem to fit the well-known logarithmic equation of Krey for fluid flow over a rough boundary.

INORGANIC CONSTITUENTS IN MOLLUSCAN BLOOD AND MUSCLE

F. R. HAYES AND D. PELLUET

Three representative Woods Hole molluscs, *Loligo*, *Mactra* and *Busycon*, provided blood and muscle for the estimation of chloride, sulphate and magnesium. Woods Hole and Copenhagen sea water served as standards. Salts were removed from muscle by water extraction with a Soxhlet apparatus. The work was a continuation of two summers' analyses at the Plymouth Station, and the chief attention was devoted to phases that had previously provided technical difficulties. From the standpoint of time the chief demands of the summer were 1) The development of an operative technique suitable for obtaining *Loligo* blood in the quantities required. 2) The elabora-

tion of a method for magnesium estimation which had sufficient accuracy for our purpose. This was achieved by the direct potentiometric titration of magnesium hydroxyquinolate (dissolved in acid) with potassium bromate. 3) A satisfactory method for sulphate estimation. Having previously failed with the benzidine method, we turned to the sodium rhodizonate method with better, but still unsatisfactory results.

The general aim of the work is to draw up as complete a picture as possible of the inorganic metabolism of the Mollusca. The results have not yet progressed far enough to warrant publication.

PHYSIOLOGY OF THE DOGFISH AND THE BLUE CRAB

F. L. HISAW AND A. A. ABRAMOWITZ

Due to a scarcity of material, we have not been able to make further progress in our investigation of reproduction in the dogfishes except to complete certain details of our previous work.

We have studied the influence of the pituitary on the pancreatic diabetes and normal carbohydrate metabolism of the dogfish, and have shown that the anterior lobe of the pituitary secretes a diabetogenic hormone. The neuro-intermediate lobe is devoid of a diabetogenic principle.

In crustaceans, we have found that extracts of the eyestalks will produce an intense diabetes within an hour after injection. A method of measuring the potency of such extracts has been devised, using the blue crab, Callinectes, as the test animal. We have shown that this diabetogenic substance is heat-stable, interspecific, active even after great dilution, and occurs chiefly in the sinus gland.

We were assisted in these investigations by Mr. D. A. Papandrea.

DECOMPOSITION OF CHITIN BY MARINE BACTERIA

CHARLES W. HOCK

Under experimental conditions, the decomposition of Limulus shell was found to be rapid in littoral sand, moderate in bottom mud, and negligible in sea water. During the decomposition process the carbon-nitrogen ratio of the shell remained constant. As a result of decomposition of the shell there was no change in total carbon and nitrogen of the sand, but there was an appreciable increase in the nitrogen of the mud. The number of chitin-decomposing bacteria was high in sand, lower in mud, and lowest in sea water.

Approximately fifteen types of chitin-decomposing bacteria were isolated from the following sources: sand, mud, water, decomposing

crabs, and the intestinal contents of the quahog, squid, skate, sand crab, dogfish, puffer and oyster. Among the readily demonstrable products resulting from the decomposition of pure chitin are ammonia, reducing substances, and organic acids.

HYDROLOGICAL INVESTIGATIONS

C. O'D. ISELIN

With the assistance of Dr. Sidney Hsiao, the available Gulf Stream sections on the Montauk Point-Bermuda line have been analyzed dynamically. The variability of the current found by this method appears to be consistent with the tide gauge observations from Miami, Charleston and Cat Cay. A preliminary report on the first two and a half years of this investigation of fluctuations in the transport of the Gulf Stream is now almost ready for publication.

Various routine duties at Harvard and at Woods Hole have required most of the remaining time. However, last spring a study was made of the downward transport of North Atlantic winter surface characteristics by the mechanism of isentropic mixing. Recently the seasonal temperature cycles at the bottom on Georges Bank and of the whole water-column 30 miles south of Montauk Point were examined.

Dr. E. F. Thompson, of the Bermuda Biological Station, has been at Woods Hole since last May, studying the local circulation system near Bermuda from the point of view of our Gulf Stream program. His coöperation and that of Mr. H. B. Hachey, of the Atlantic Biological Station at St. Andrews, have greatly contributed to the success of the whole project.

DENITRIFYING AND NITRIFYING BACTERIA IN THE SEA

BLODWEN LLOYD

The reduction of nitrates to nitrite and finally to nitrogen occurs readily in sea water enriched with organic matter and nitrate and having a high bacterial content. Temperature regulates the rate but not the final amount of nitrate-reduction. Hydrogen ion concentration at 8.0 to 8.4 favours denitrification, and at pH 6.0 retards but does not inhibit it entirely. Dissolved oxygen also retards denitrification, but even in oxygen-saturated sea water it still occurs. These factors are significant, but the limiting factor is very clearly the amount of available organic matter: in sea water enriched with 2.5 gms potassium nitrite per litre and 1.0 milligm peptone per litre, the nitrite loss is very slight.

Laboratory experiments confirm the oceanographic observations made on samples collected by the "Atlantis." Samples from neritic areas denitrify readily; pelagic samples with fewer bacteria and less organic matter, not so readily. During bacterial denitrification there is increased alkalinity, and in samples of several weeks' standing, calcium carbonate is precipitated. Several strains of such chalk-precipitating bacteria were isolated, from samples procured both from "Atlantis" cruises and from the research vessel of the Sponge Fisheries investigations off the Bahamas. The grains of calcium carbonate precipitated by non-denitrifying heterotrophs were not laminated; those precipitated by denitrifying heterotrophs showed concentric laminations frequently. This may throw some light on the origin of some marine oolites, and the problem is being investigated further.

Following upon the work of Dr. Waksman and Dr. Carey on nitrification in sea water, a search was made for the causative micro-organisms. Bacterial cultures similar to the recently-described *Nitrosocystis* of Mlle. Winogradsky were found, but could not be obtained free from saprophytic bacteria, nor could such cultures be repeated at will. The controlling factors are as yet imperfectly known.

From the large-scale nitrifying experiments of Dr. Rakestraw and Dr. von Brand, our attempts to isolate nitrifying bacteria were unsuccessful, but we found, however, abundant *denitrifying* saprophytes. It is hoped to continue and complete this work.

FOOD AND FEEDING MECHANISMS OF COPEPOD NAUPLII

JOHN H. LOCHHEAD AND MARGIT S. LOCHHEAD

A preliminary attempt was made to determine the feeding mechanisms in some of various pelagic copepod nauplii. Each species was found to have its own characteristic mode of swimming, with differences in the currents created which probably are of importance in feeding. Efforts to observe the mechanism of food capture were not satisfactory because all the nauplii fed only very sparingly under laboratory conditions. Of various types of food which were tried those that were eaten most freely were *Arbacia* sperm and the large green flagellate, *Platymonas*. In a few cases these half filled the gut within 2–4 hours. Smaller numbers were taken of certain ciliates. Immobile objects such as yeast cells, *Nitzschia*, and various types of small particles, were scarcely eaten at all. This result is in general agreement with some earlier observations on fresh-water forms, for which flagellates were found to be perhaps the most important source of food. The rate of feeding, however, was always much less in the

marine than in the fresh-water species. The nature of their food in the sea remains unknown, but in those taken at Woods Hole the gut contents were nearly always green.

STUDIES IN PHYSICAL OCEANOGRAPHY AND METEOROLOGY

R. B. MONTGOMERY

1. A report on simultaneous observations of humidity at various levels between 1 and 38 meters above the ocean surface made from "Atlantis" in 1935 has been computed. These data have yielded useful information on the turbulent and laminar boundary layers above the ocean surface. In particular, tentative information was derived on the factors determining the hydrodynamic character of the surface: the most important factor appears to be the temperature difference (water) − (air), the surface being "rough" when this is positive and "smooth" when this is about zero or negative. The work gives considerable advancement in the development of a practical method of determining the amount of evaporation from the ocean surface, applicable also to the transfer of other properties between ocean and atmosphere, such as momentum and carbon dioxide.

2. Studies of isentropic mixing in the ocean have been continued.

3. A study of the kinematics and dynamics of the waters in the Straits of Florida has been initiated.

BACTERIOLOGICAL DECOMPOSITION OF ORGANIC COMPOUNDS

HELEN NORRIS MOORE

The number of proteolytic organisms in sea water, and various media for their differentiation were investigated. The two media used contained 1.0% peptone, 5% gelatin, 1.5% agar, and 0.02% cystine, dissolved in (a) sea water or (b) 10% salt solution, both at pH 7.5. Sterile whole laked rabbit blood (providing protein rich in sulphur linkages) and a solution of bismuth citrate (to indicate hydrogen sulfide production) were added to each plate before pouring.

Sea water from various depths in Buzzards Bay and brine from chopped sealskin pelts were plated on these media and incubated at room temperature for from 2–5 days.

No samples grew on the 10% salt medium. The sea water medium showed growth of all sea water samples in 48 hours, indicating a stimulation possibly due to the bismuth or cystine or blood. No correlation between depth of sampling and numbers of hydrogen sulfide formers appeared.

COLOR CHANGES AND PIGMENTATION IN FLATFISHES

CLINTON M. OSBORN

During the summer of 1939 experiments were carried out concerning *three* aspects of pigmentary behavior in flatfishes (Summer Flounders, Winter Flounders and Sand Dabs).

1. The effects of artificial illumination on the production of pigment in normally unpigmented areas.

2. The effects of total blinding and semi-blinding on the rates and degree of background adaptation.

3. The reactions of melanophores of flounders to sympathetic and parasympathetic drugs.

A technique of subjecting the ventral surfaces of adult summer flounders to continuous diffuse light of constant intensity will be described. Both direct and reflected light have been used with success. Preliminary experiments on 22 animals indicate that illumination of the normally unpigmented ventral surface causes pigment (in apparently normal melanophores) to develop there. The first macroscopic appearance of ventral pigment followed 7 days of continuous illumination at the highest intensity used. Considerable melanin can be grown in 30 days, and extensive pigmentation occurred in a few fishes treated 7 weeks.

All of the flounders used in these experiments were in a physiological condition causing pigment dispersion in the melanophores on the dorsal surface. This was accomplished either by allowing these fishes to background-adapt to the black walls and ceiling of the experimental tank or by blinding fishes which previously had been black adapted. Vision is not essential, therefore, to the experimental development of ventral pigment.

Fishes appeared to experience discomfort from ventral illumination as manifested in repeated attempts to avoid it by coming to rest on their edges with the ventral surface against a vertical wall.

QUANTITATIVE STUDY OF THE FORAMINIFERA

FRANCES L. PARKER

It is believed that by establishing the relationship of the different genera and species of the foraminifera at the various depths and temperatures found along the east coast of the United States, that the study of samples from cores will be rendered much more exact. For this purpose a quantitative study of five different lines of samples

from the beach to the outer edge of the shelf, together with scattered samples from the slope, is being made.

Evidence has been found for several ecologic zones running parallel to the coast. Faunal differences have also been found between the more northern stations and those further south. The foraminifera of about half the stations have been counted and their precise relationship by percentage and abundance worked out in order to give as precise data as possible.

ECOLOGY OF SAND BEACH ORGANISMS

ROBERT W. PENNAK

In an attempt to establish certain ecological relationships of the microscopic Metazoa (especially the copepods) inhabiting their interstitial waters, four beaches in the vicinity of Woods Hole were studied between June 10 and July 22, 1939. Greatest emphasis was placed on a typical beach near Nobska Point; the other locations, differing from it considerably in morphology and exposure, were studied in order to ascertain the effects of heavy wave action, little wave action, and high particulate organic content on the distribution of the organisms.

Sand samples were collected vertically between the surface of the sand and a depth of 16 cm., and horizontally from the high tide line to below low tide level. In the laboratory the organisms were washed out of the sand and preserved for a quantitative and qualitative study to be carried out during the coming winter.

In addition, a series of measurements of the water content of the sand over the entire width of the beach was made. Dissolved oxygen and free carbon dioxide content of the capillary water were also frequently determined.

THE FORMATION OF THE PRIMARY FILM IN THE PROCESS OF FOULING OF SUBMERGED BODIES

AUSTIN PHELPS AND MARGARET HOTCHKISS

This work was initiated by the Bureau of Construction and Repair of the U. S. Navy Department. A detailed study has been made of the effect of the nature of the surface exposed and of the nature of the paint covering the surface upon the development of bacteria forming the primary film. A detailed study has also been made of the chemical nature of this film. A number of stations along the Atlantic seaboard have been selected for submerging painted surfaces for varying periods of time at different seasons of the year.

CHEMICAL INVESTIGATIONS

NORRIS W. RAKESTRAW

Work has been continuing on the decomposition and regeneration of nitrogenous organic matter in sea water. One paper, covering the results of the last two years, has recently been published. Work is now in progress to ascertain the effect of temperature and source of water on the nature of the decomposition cycle. A start has also been made to determine the part, if any, played by gaseous nitrogen. Contrary to the earliest investigations, indications have been found of the existence of intermediate nitrogen compounds between the formed organic matter and the ammonia resulting from decomposition.

An investigation of the changes in gaseous dissolved nitrogen in stored sea water has been continued, and nearly completed. The possibility of a slow fixation of gaseous nitrogen seems rather more likely than it did previously.

Work was completed on the problem of the helium and neon content of sea water and its relation to oxygen. The previous report of such correlation between the oxygen minimum and one of helium and neon was definitely disproved. A paper covering this work was published recently.

A comparison has been made between the oxygen, nitrate and phosphate concentrations at a number of deep sea stations to determine more accurately the relation in the neighborhood of the oxygen minimum. The results from a year's chemical survey of the line of stations between Woods Hole and Bermuda are also being correlated.

During the last summer Mr. Arnold N. Morton undertook an investigation of the growth of diatoms in artificial sea water prepared from highly purified salts. This work has not yet been completed.

A start has been made on the determination of the rate of oxygen consumption in deep waters, at the oxygen minimum and below. Due to the extremely low rate found the investigation will probably continue for a long time.

STUDIES ON THE BIOLOGY OF THE GULF OF MAINE AND OF THE PHYSIOLOGY OF DIATOMS

ALFRED C. REDFIELD

A report is in preparation on the distribution of chaetognaths in the Gulf of Maine in relation to the current systems of that body of water. A study is now in progress of the physiology and biological chemistry of algae under conditions of nutrient deficiency, a condi-

tion which must be of perennial occurrence during the life of marine phytoplankton in nature.

BACTERIOLOGY OF MARINE MUDS

C. E. RENN

The fine, inorganic materials of marine muds adsorb soluble and colloidal proteinaceous materials from decomposed plankton. This adsorption is very marked and rapid. In shallow, stirred waters the adsorbed materials are carried to the bottom in the sediments. By this mechanism a variable fraction of the organic matter of the sea becomes concentrated in the mud.

Under aerobic conditions it has been determined that the presence of adsorbing materials has little or no effect upon the rate at which decomposition of plankton materials takes place.

An efficient, inexpensive respirometer was designed and constructed to give continuous measurements of biological consumption of oxygen in muds and systems rich in organic matter that cannot be studied conveniently by standard chemical methods.

STUDIES ON FISHES

WILLIAM C. SCHROEDER

1. *The Deep Water Fauna around Cuba.* During March, April and May "Atlantis" made a second deep sea bottom trawling cruise around Cuba thus continuing the investigation of the fishes and other animals in this region started the previous year. Out of a total of 174 hauls, made in depths ranging from 315 to 2610 meters, 137 were successful. The gear consisted of 35 and 60 foot otter trawls, and 10 and 14 foot "Blake" trawls, the same types as were used last year.

Again good catches were made, with several hundred species of fish and a possible seven or eight hundred species of invertebrates, exclusive of foraminifera. New species will probably reach 25 or more, these being in addition to the 100-odd taken in 1938.

2. *Migrations of Gulf of Maine Cod.* From time to time progress was made in a report dealing with the migrations of cod living in this region.

3. *Fishes of the Western North Atlantic.* A general revision of the fishes of our Atlantic Coast was started this year by various ichthyologists scattered throughout the country. Dr. H. B. Bigelow and myself have agreed to work up the sharks and skates and also the Family Gadidae, the codfishes, and have assembled considerable data toward the completion of this report. We are also making a

revision of the Genus Mustelus and have examined nearly all the material in the Museum of Comparative Zoölogy, Cambridge, and in the National Museum, Washington.

INTERNAL WAVES

H. R. SEIWELL

Five deep anchor stations of approximately 27 hours duration each in the southern North Atlantic and Caribbean Sea, and one of 5 days duration, 150 miles northwest of Bermuda, were successfully completed during the year, and continuously repeated records of temperature at a series of fixed depths, between surface and 1100–1200 meters, obtained for internal wave investigations. At the localities sampled, temperature variations at fixed depths frequently exceeded 0.5° in 24 hours, apparently resulting from lunar diurnal and lunar semidiurnal vertical oscillations of the water particles.

As a result of the internal wave phenomenon, time variations of sea water properties at fixed depths may induce discrepancies of significant magnitudes in computed dynamic topographic and circulation patterns, as undertaken by the usual oceanographical procedure. Thus, it was desirable, as a first step, to complete a report, based on actual examples, which illustrated magnitudes of discrepancies to be expected in practical oceanographical investigations of the Western Sargasso Sea and of the Gulf Stream System off the American coast, and which offers appropriate suggestions for estimating significance of observed horizontal variations of sea water properties.

Actual analysis of the problem has been undertaken from both statistical and dynamical viewpoints. By the former, the establishment of dominating lunar diurnal and lunar semidiurnal frequencies, has permitted treatment of the geometrical properties of the derived harmonic coefficients of vertical oscillations so as to bring out detailed information on the nature of the phenomenon. In the dynamical treatment of the problem, computation of vertical displacements based on vertical distributions of density in the sea, has shown good agreement with observed values.

During the year at various times, I have been assisted by Kenneth Arnold, Andrew Stergion and Gladys Seiwell. The problem is partially supported by a grant from the Penrose Fund of the American Philosophical Society.

PHYSICAL OCEANOGRAPHY OF THE GRAND BANKS REGION AND LABRADOR SEA

FLOYD M. SOULE

Manuscript for the section on oceanography of U. S. Coast Guard Bulletin No. 28 (season of 1938) was completed during the months of January, February and part of March. This work included a quantitative consideration of the effect of a storm-produced, hypothetically uniform, vertical mixing of the upper 100 meters. The peripheral circulation in the upper layers of the Labrador Sea in 1938 was investigated by means of volume of flow, mean temperature, and heat transfer across four sections. Newly collected data on oxygen distribution along a longitudinal section through the northern part of the Labrador Sea were studied, adding information regarding the source of the bottom water of the Labrador Sea.

The months of April, May and June were spent on the oceanographic vessel of the International Ice Patrol Force, the U.S.C.G. Patrol Boat *General Greene*, supplying dynamic topographic charts of the Grand Banks region to the Ice Patrol cutters *Chelan* and *Champlain*. During this period four current surveys of the critical area were made, the resulting charts being referred to the 1000-decibar surface although at most of the oceanographic stations the temperature and salinity measurements extended to a depth of 1400 meters where the depth of water permitted. In this work 201 oceanographic stations were occupied. Between July 10 and July 15 the *General Greene* occupied 25 additional oceanographic stations from the surface to as near bottom as was practicable on an abbreviated post-season cruise in the Labrador Sea. The stations on this cruise were disposed in the form of a section from South Wolf Island, Labrador, to Cape Farewell, Greenland.

The available evidence collected by the International Ice Patrol regarding the existence, shape, and depth of a motionless surface in the Labrador Sea and the region immediately eastward of the Grand Banks was assembled and presented at the Seventh Triennial Assembly of the International Union of Geodesy and Geophysics in Washington. This evidence pointed to the existence of an approximately level motionless surface lying at a depth of about 2000 meters in the Labrador Sea and somewhat deeper (about 2000 or 2500 meters) east of the Grand Banks, and was contributed by patterns of flow, bottom temperatures, a volume transport balance, temperature-salinity correlations and a deep-water isentropic analysis.

Since September the rest of the year has been used in digesting

the data collected on the 1939 season and post-season cruises of the *General Greene* and in preparing for publication the oceanographic section of U. S. Coast Guard Bulletin No. 29 (1939 season).

STUDIES IN SEDIMENTATION AND IN SUBMARINE GEOLOGY

H. C. STETSON

Two trips were made on "Atlantis" in which cores were obtained from hitherto uncharted sections of the continental slope. With these, the first stage in the field work in the study of the Pleistocene history of the continental shelf and neighboring ocean basin has been completed. Most of the laboratory work has been finished and the report is under way. As has been previously stated this is being done in collaboration with Dr. J. A. Cushman, Miss Frances L. Parker and Dr. F. B. Phleger. The first part of Dr. Phleger's report has been published by the Geological Society and he is at present engaged in writing the second. Dr. Cushman and Miss Parker have been somewhat delayed by their duties in connection with the U. S. Geological Survey.

A chapter on the continental shelf was written for the book "Recent Marine Sediments" published by the Committee on Sedimentation of the National Research Council and a report on the shoals of Vineyard and Nantucket Sounds is in preparation from samples collected three years ago.

The Soil Mechanics Laboratory of the Harvard Engineering School and the American Society of Civil Engineers are conducting a program for the testing of different types of sedimentary deposits for foundation purposes. Through our assistance, sampling with various kinds of coring tubes was carried out in a pit in West Falmouth. The results of this and other tests, which Dr. M. Juul Hvorslev has kindly placed at our disposal, have considerable bearing on problems encountered in taking bottom cores at sea. With these data, it is planned to construct a coring tube which it is hoped will eliminate some of the undesirable features which all coring tubes at present possess.

A STUDY OF THE HYDROGRAPHY OF THE BERMUDA AREA

E. F. THOMPSON

The data for the Bermuda region of the Sargasso Sea have been examined. Particular attention has been given to the salinity-temperature correlation and seasonal variations of the current pattern

and other physical characters. While this work should help to give a better picture of the conditions in the Sargasso Sea, its chief purpose is as part of the coöperative Gulf Stream investigation.

DEPLETION AND REGENERATION OF BLOOD SERUM PROTEINS IN MARINE ELASMOBRANCHS AND TELEOSTS

ABBY H. TURNER

The study of blood serum proteins in different groups of fishes was continued in 1939, on the smooth dogfish, *Mustelus canis*, on the tautog, *Tautoga onitis*, and on a few other species, by determination of colloid osmotic pressure, refractive index of the colloid fraction, protein nitrogen (analyses by Helen Murphy), and water content of the muscles.

Results. Nine specimens of *Mustelus canis*, six of *Tautoga onitis* and one *Prionotus carolinus* withstood extensive bleedings from three to seven times. The experimental work leads to the following statements.

1. That the fish were suitable for study was shown by the close correspondence between the determinations on each first sample and values obtained in previous years on these species.

2. *Mustelus canis* and the teleosts show evidence of reserve protein supplies in that the protein of the serum falls less rapidly than the corpuscular volume. The protein nitrogen falls less than the colloid osmotic pressure indicating that proteins of higher molecular weights are retained preferentially.

3. Regeneration of proteins was shown in three instances, one dogfish, one tautog, and one robin, in all of which conspicuous rises in protein values occurred, except for the colloid osmotic pressure in the two teleosts. This last indicates again that proteins of the larger molecular weights, certainly in the teleosts, are more readily manipulated by the fish than the smaller ones which are associated more closely with the colloid osmotic level.

4. Depletion of serum proteins to a level of colloid osmotic pressure as low as one third or one fourth the original value was not followed by any perceptible edema. That this osmotic change was not without some influence was, however, shown in several instances by a rise in the percentage of water in the muscles. This was seldom conspicuous.

5. The evidence on the whole seems to relate the proteins more closely to the nutritive cycle than to the control of water balance between blood and tissues.

STUDIES ON THE NITROGEN CONTENT OF THE PARTICULATE MATTER IN THE SEA

THEODOR VON BRAND

A study of the nitrogen content of the particulate matter in the region of the oxygen minimum layer was made at seven stations (two from the Caribbean region, three from the slope water and two from the Sargasso Sea). Wherever possible closely spaced samples were analyzed from a region above the oxygen minimum layer, through the layer itself and a region below it. No indication was found that greater irregularities in the amount of particulate nitrogen occur in the region of the oxygen minimum. It should, however, be emphasized that conclusions from these findings can be drawn only with great reserve, since, so far, nothing is known about the C:N ratio of the particulate matter at different levels. Furthermore there is at the present time no way to decide how much of the particulate matter represents living organisms and how much dead material, or even residues from decomposition processes.

In addition six stations from the Cuban cruise were analyzed. Relatively high and uniform values were found at all levels.

STUDIES IN MARINE MICROBIOLOGY

SELMAN A. WAKSMAN

During the year 1939, eleven investigators in Marine Microbiology spent varying periods of time at the Oceanographic Institution. The work dealt with a variety of problems, which can be briefly summarized as follows:

1. The chemical nature of organic matter in the sea bottom and in decomposing algal material—Selman A. Waksman and C. M. Weiss.

2. Decomposition of organic matter in marine muds, with special emphasis on the liberation of the nitrogen in available forms—C. E. Renn.

3. Occurrence of denitrifying bacteria in the sea bottom—Blodwen Lloyd.

4. Occurrence of nitrite and nitrate forming bacteria in sea water and in the sea bottom—C. L. Carey.

5. The rate of oxidation of the dissolved organic matter in sea water—Claude E. ZoBell and Mrs. H. N. Moore.

VITAMIN A AND RETINENE IN SQUID EYE TISSUES

GEORGE WALD

All attempts to identify vitamin A in invertebrates have so far failed. This is interesting from an evolutionary viewpoint; and because the zooplankton, primarily invertebrate, form the channel through which carotenoid vitamin A-precursors supposedly flow from their ultimate source, the phytoplankton, into the marine invertebrates, many of which contain huge stores of vitamin A.

The high concentrations of vitamin A found in vertebrate retinas suggested an examination of squid eye tissues for this substance. A preliminary extraction of light adapted retinas with benzine yielded a greenish-yellow pigment, which, when tested with antimony chloride displayed the general carotenoid reaction, a deep blue color, due in this instance to sharp absorption bands at about 615 and 664 mμ. These bands are commonly specifically associated respectively with vitamin A and retinene. Further exhaustive extraction of these tissues yielded retinene alone, in relatively enormous quantities.

In vertebrate retinas, retinene is a specific intermediate between the visual pigment, rhodopsin, and vitamin A. Under the conditions of the present experiments, no retinene would have been found in a vertebrate retina. Its presence here suggests that the visual system of the squid is chemically closely related to that found in vertebrates, yet differs in arrangement in some still unknown manner.

THE CIRCULATION IN THE GULF OF MAINE AND DIRECT MEASUREMENT OF CURRENTS

E. E. WATSON

With the assistance of Helen Hay all charts of the dynamic isobaths for the 1933–34 survey have been prepared for publication, as well as others showing distribution of temperature and salinity. It is clear that for the spring and summer months the dynamic methods employed give substantially the same picture as that presented by Bigelow in 1924, so that the two presentations are mutually corroborative. For the winter months there is considerable evidence of a major change in the circulation of the Gulf, particularly across Georges Bank. The water from the Gulf moves directly across the Bank instead of peripherally around it as in the summer. Major changes take place in March and in September. The observations for Georges Bank are sparse, particularly on the south side, but the in-

vestigations of the Bank commenced in September should add to our knowledge of conditions there, and complete the picture of the circulation in the Gulf of Maine.

The recording current meter has definitely proved itself suitable for use at sea, either in deep water from "Atlantis" or in shallow water from "Asterias." During tests last August "Atlantis" was anchored in about 900 fathoms off Montauk Point. Current measurements were made down to 400 meters, but mainly at 200 meters, the level of the oxygen minimum layer. Owing to difficulties in keeping the ship anchored and the loss of the anchor itself the interpretation of the measurements obtained is uncertain. But valuable experience was gained in the use of the single insulated steel cable which supported the meter and in the operation of all parts of the measuring system. While use will suggest further improvements in the instruments the fundamental difficulty in deep sea current measurements from "Atlantis" now lies in the problem of anchoring the ship.

LIGHT PENETRATION OBSERVATIONS

LESTER V. WHITNEY

A photocell amplifier was adapted for measuring the angular distribution of underwater light intensity. After testing the apparatus near Woods Hole, a set of readings was then obtained from the "Atlantis" at the edge of the continental shelf. These observations, as well as the later ones taken from the "Asterias," were extremely satisfactory and are now being analyzed.

THE RATE OF OXIDATION OF THE DISSOLVED ORGANIC MATTER IN SEA WATER

CLAUDE E. ZOBELL

By determining the oxygen content of sea water before and after incubating in glass-stoppered bottles it was found that the bacterial oxidation of the organic matter of sea water from the Woods Hole region consumed from 0.5 to 1.5 cc. of oxygen per liter in 10 days at 22°C. Water samples collected from the oxygen minimum layer in the Sargasso Sea consumed only 0.46 cc. of oxygen per liter in 10 days at 22°. Untreated, silk filtered and sintered-glass filtered portions of a sample of surface water collected June 24 from Buzzards Bay consumed 0.86, 0.60 and 0.49 cc. of oxygen per liter respectively. These observations were repeated with similar results.

The average results of several determinations revealed that at 22°C. about 50% as much oxygen was consumed in 10 days as was

ultimately consumed by the bacteria in stored sea water after 60 days. After 20 days between 70% and 80% as much oxygen was consumed as in 60 days.

The rate of oxidation of organic matter in sea water as indicated by oxygen consumption by bacteria is independent of the oxygen tension within the examined ranges of 0.31 to 12.74 cc. of oxygen per liter.

During the first two days of incubation at 22° bacteria in stored sea water were found to consume an average of 14.2×10^{-12} cc. of oxygen per cell per hour. The rate dropped to 9.5×10^{-12} cc. of oxygen per cell per hour after five days and from the fifth to the tenth day of the experiment the bacteria were consuming an average of only 2.6×10^{-12} cc. of oxygen per cell per hour. The decreasing respiratory rate is attributed to the progressive utilization of the more readily oxidizable fractions of organic matter occurring in sea water leaving only the more refractory fractions.

Confirming observations made recently at the Scripps Institution of Oceanography it was found that nitrites appeared in most ammoniacal sea water solutions inoculated with 10 cc. of raw sea water collected from Buzzards Bay or Vineyard Sound provided the concentration of ammonium was low. More than 10 mgm. of ammonium per liter seemed to be inimical to the activities of the marine nitrifying bacteria although terrestrial nitrifiers tolerate over ten times this concentration of ammonium. There was no evidence that low concentrations of organic matter (10 mgm./1) inhibit nitrification provided the oxygen is not depleted from the water.

Progress was made in the perfection of a device for collecting samples of water from any depth for bacteriological analysis.

List of Contributions

LIST OF CONTRIBUTIONS

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